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GRAPHANT: A FORTRAN PROGRAM FOR THE SOLUTION AND GRAPHIC DISPLAY OF GAIN AND PATTERNS FOR WIRE AND LINEAR ANTENNAS IN THE PRESENCE OF LOSSY GROUND

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ABSTRACT:

An interactive computer graphics antenna gain pattern computation and display program for real-world antenna systems is presented. The use of the program as a teaching tool at the Naval Postgraduate School is discussed. Methods for applying the program for the synthesis and design of complex antenna systems are indicated. Research applications include techniques for rapid inspection of gain equations of newly developed antennas. A ship motion model is developed for studying the effects of electrical geometry variations caused by ship motion in heavy seas on maritime antenna systems and a dynamic presentation of pattern variations is made.

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A. INTRODUCTION

Anyone who has attempted to correlate the actual performance of HF and VHF wire antennas operating in a real-world environment to the "highly sanitary," theoretical radiation patterns and gain which proliferate in text books and handbooks will immediately recognize the need for a simple method of predicting antenna performance in the presence of the earth. This report describes the development and use of a computer tool, which enables anyone with a working knowledge of Fortran and a free-space radiation pattern and mutual impedance formulation to analyze and design antenna systems of arbitrary orientation above a specified lossy plane earth.

It serves as both a teaching aid and a design tool. In instructional use, it provides quick interaction via a graphics display of antenna parameters and radiation patterns plots. In seconds, a student can observe the performance of several popular HF/VHF antennas in any plane earth configuration he chooses. Equivalent digital computer/plotter turn-around time is in excess of 1 hour and manual calculation time on the order of days. The program firmly convinces the student that the antenna system is composed of the antenna plus its environment.

For the communications system designer, rapid evaluation of antenna systems enables him to choose an antenna type and orientation which will enhance the performance of the total system rather than arbitrarily guessing which antenna package might be suitable. When new antenna types are developed, their radiation pattern and impedance equations can readily be added to the basic calculation package and the full potential of the antenna may be painlessly determined, not just for the usual, mystical free space environment, but for the surroundings in which the radiator will be used. Using an HF Ionospheric Propagation Prediction program which can return optimum radiation angles for a specified path and time, a systems designer can synthesize an optimum antenna pattern for the particular situation under investigation. The optimum may be manually entered and each design iteration compared with the optimum. The pattern Save and Recall options are used to arrive at the best type antenna and orientation available to him.

Previous work on antenna patterns in the presence of ground is widely scattered in the literature. Specific antenna types are referenced in the appendices. The initial incentive for this investigation was to increase the usefulness of an antenna radiation pattern subroutine for HF antennas, currently in use as part of a HF Ionospheric Propagation Prediction program written by ESSA[1]. The gain and input resistance equations from this report with some modifications and corrections were used. Equations programmed are included in Appendix C.

The program as presently configured assumes a current distribution on the antenna. The consequences of this are small errors in terminal impedance with a corresponding discrepancy in gain value. Radiation patterns are affected very little by the differences between assumed and actual currents. To calculate exact current distributions would be prohibitive in both time and programming effort, considering the limited worth of the more exact gain figures which would result.

1 Ref: ITS 78 Report.

B. BRIEF DESCRIPTION OF PROGRAM

The program consists of two basic parts:

1. The solution of antenna pattern equations for radiators of arbitrary orientation above a flat earth of specified ground constants (conductivity and permitivity). Gain values are calculated from terminal impedance expressions containing self (free space) and mutual (coupling between the antenna and its image) effects.

2. The graphics display portion which displays program input parameters specifying antenna type, size, orientation, ground constants and special features such as recall and storage of patterns. This part of the program also generates power intensity plots vs. azimuth and elevation angles and displays these radiation patterns on the graphics screen. Gain values can be displayed in conjunction with the patterns.

Subroutines for special functions which are usually found in wire antenna patterns and impedance formulae and numerical quadrature calculations are included for the convenience of persons wishing to apply their own specific antenna to the program. The user who wishes to do this must provide pattern equations for his antenna for arbitrary orientation. The effect of ground reflections and the selection of observation angles is provided by the program itself.

Special features available to the user are:

1. Plotting patterns on a log scale vs. linear.

2. Storage and recall of patterns for comparison purposes.

3. Ability to generate a desired pattern shape (via light pen) which is stored and recalled for comparison.

4. Simple ship-ocean model for dynamic simulation of shipboard antenna systems.

When the program is used at USNPGS, the XDS 9300 digital computer core limitations restrict the calculation and viewing of one pair of cuts in the 3 dimension geometry (i.e. one azimuth rotation at one specified elevation angle and one zenith to horizon elevation cut.) Typical time for a pattern calculation is 15 seconds, with a simple dipole requiring 9 seconds and a vertical monopole with ground screen up to 2 minutes. Seven common antennas are currently programmed:

1. Arbitrary Tilted Dipole

2. Vertical Monopole

3. Vertical Monopole with Ground Screen

4. Inverted L

5. Sloping Long Wire

6. Rhombic

7. Vertical Half-Rhombic

More complex programs for arrays such as Yagis, Log Periodic Dipoles and Monopoles, and curtains will require fairly long calculation times due to the extensive mutual impedance calculations.

C. DYNAMIC ANALYSIS OF SHIPBOARD ANTENNAS

The ease of obtaining the effect of the earth on antenna performance prompted the investigation of the programs potential to display the effect of typical ship motion of shipboard HF antenna radiation. The equations for an arbitrary tilted dipole, sloping long wire and vertical monopole were already in the form to allow variable tilt angle. By programming a ship-ocean model that reorientates the antenna with ship motion (roll and pitch), it is possible to show slow but dynamic pattern changes with sea surface as a function of sea state and ship direction for a chosen type of vessel. This simplified model rocks the antenna in two planes as the ship responds in roll and pitch to ocean waves but still assumes a plane ocean reflecting surface. For medium and heavy seas, the results indicate an appreciable re-lobing effect and show that the variation in signal at a particular observation angle may be as high as 20 db.

This is an additional factor which should be considered when assigning locations for antennas in new ship designs. Present efforts at evaluation of these antenna locations do not include sea state perturbations.

The next stage of investigation of ship motion effects will include a variable geometry for the sea surface to replace the plane shape. At low HF the effect might be approximated by a partially random "fuzzy" surface while for UHF the distances are large in term of radio wavelengths and the model could be more nearly that of a rolling surface contour.

The final results of these extensions will be of benefit to the antenna locator, as previously explained, as well as to communications managers. Depending upon the sensitivity of the total communications link to antenna lobe structure, communications procedures for a given frequency may be improved by insight obtained from the investigation of sea state effects.

D. RECOMMENDATIONS

The radiation equations for most of the antennas do not include the arbitrary geometry factors needed for ship motion effects study and should be expanded to include them. Gain calculations depend upon input resistance which in the case of the sloping long wire and others do not include mutual effects. Where possible and where warranted, these effects should be included by deriving coupling terms for input impedance equations. (This will not alter the shape of the radiation patterns and affects only the magnitude of the fields and hence the gain).

Array antenna equations exist in the literature and should be carefully verified and adapted for inclusion in the plotting program.

When this program is used for matching patterns produced by HF propagation prediction programs, a convenient data interfacing technique (such as tape) should be developed for use between the graphics system and the lager general purpose digital machine used in the prediction calculations.

APPENDIX A

DETAILED PROGRAM DESCRIPTION

Appendix A

Section III contains a description of program operation. The program is divided into processors, program subsections that perform the major computational tasks. Processor operation and interaction are described.

1. PROGRAM OPERATION

The program displays a data and option command input format at the graphics terminal (see figure A-1). The program operator enters applicable parameters values for antenna geometry, environment, and option commands using text editing techniques. A blank graphics block is then displayed at the CRT. Trial patterns may be manually entered in this block using graphics editing techniques. Manually entered patterns will be displayed with all subsequently computed patterns allowing the operator to compare computed patterns with trial patterns on the CRT. Exercising the reinitialization option will erase the trial pattern.

The program computes horizontal and vertical gain patterns and displays them at the graphics terminal. The horizontal pattern is computed with zenith constant at the inputed value for Θ' and azimuth varied from 1 to 360 degrees by one degree increments. The vertical pattern is computed for azimuth constant at the inputed value of ϕ' and zenith varied from 1 to 90 degrees by 1 degree increments. Linear and log displays are available. If a log display is not ordered with the log pattern option command, linear patterns will be displayed.

Patterns are saved by exercising the save pattern option. Pattern vector data is stored in the digital machine in a save array when save is ordered. Exercising the recall option will cause patterns saved in the save array to be displayed.

Use of save and recall options allows simultaneous display of saved and current patterns for comparison purposes.

A dynamic simulation of a shipboard antenna mounted on a rolling pitching ship in a stop-action type of presentation is programmed. Entering sea state and direction in the data format causes the simulation to operate. Sea motion is resolved into ship motion and ship motion into antenna parameter variation. Patterns are computed and displayed at 10 degree intervals of wave period. Sea state 0 must be entered to by-pass the dynamic simulation if it is not desired.

Appendix F is operating instructions for use of the program implemented at the Computer Graphics Laboratory, U. S. Naval Postgraduate School, Monterey, California. Figure A-16 is a schematic of the graphics computer system at this facility.

2. PROCESSOR DESCRIPTION

A processor flow chart is presented in figure A-2. Processor operation and interaction is described below.

A. The Parameter Format Processor initializes the display graphics and text data blocks and displays the text format for parameter and program options commands input.

B. The Parameter and Options Input Processor is used to enter problem parameters and program option commands using the format provided by the previous processor. The parameter and options input processor requires entry of all parameters each time the program is initialized. All other utilizations of this processor require changing only individual parameters as desired. If the reinitialization option is selected by the operator, the parameter format processor is branched to from the parameter and options input processor.

C. The Pattern Manual Entry Processor displays a blank graphics data block. By manually editing this data block, the operator may draw a pattern that will be displayed with all subsequently computed patterns. Erasing this manually entered pattern must be done by reinitializing in the parameter and options command processor. If no manual pattern is desired, this processor may be terminated without entry being made.

D. The Environmental Constants Processor computes the values of problem constants that are functions of antenna parameters and environmental conditions and not dependent upon observation angles.

E. The Input Resistance Processor computes a value for input resistance of the antenna entered in the parameter and options input processor. If the equations in the gain processor assume a nominal value of input resistance, a value of 1.0 is assigned to input resistance.

F. The Observation Angle Constants Processor computes values of problem constants that are functions of observation angles for those observation angles for which the antenna gain is to be computed.

G. The Gain Processor computes the gain of the antenna selected in the parameter and option command input processor at the selected zenith angle all integer values of azimuth angle from 1-360 degrees, and the selected azimuth angle and all values of zenith angle from 1-90 degrees. These two gain vectors are the horizontal and vertical gain patterns.

H. The Normalize and Max Gain Processor selects the maximum value of gain from both horizontal and vertical linear patterns and normalizes both patterns with respect to this maximum value. This operation is required to scale patterns for graphics display. The absolute value of maximum gain is computed and its $\log_{10}$ taken. This value is displayed in the text data format.

I. The Log Gain Processor operates if the operator manually selects the log gain option in the parameter and options command input processor. The horizontal and vertical linear patterns are converted to logarithmic. patterns with a 30 db range of ($10\log_{10}$max gain) to ($10\log_{10}$max gain). These patterns are renormalized by the log gain processor.

J. The Pattern Display Processor is a two part processor which displays the horizontal and vertical patterns at the graphics terminal.

K. The Pattern Save Processor is a two part processor which operates if the horizontal save and vertical save option are selected by the operator in the parameter and option command input processor. They may be independently selected. This processor transfers the pattern currently displayed by the display processor to storage in the digital machine in a save array. Entering a pattern in a save array destroys the pattern previously saved so care must be exercised to bypass this processor if saving the pattern for several compute cycles is desired.

L. The Display Saved Patterns Processor operates when the recall option has been selected by the operator. The processor recalls the patterns saved in the save array and displays them at the graphics terminal. Operation of this pattern does not destroy data in the save array.

M. Dynamic Processor. This processor computes and displays a simulation of shipboard whip, dipole and sloping longwire antenna patterns. Entry of an integer larger than 0 in ISEA will cause this processor to operate. The processor computes sinusoidal ocean waves with magnitude dependent upon sea state. Ship roll and pitch which are functions of ship type, sea state and relative direction of the seas are computed. Parameter variations caused by ship motion are computed and the normal compute loop entered with the modified values of antenna parameters. The patterns are computed and displayed and the gain at the Θ' and ϕ' inputed in the parameter input processor is displayed under SIGL in the text data format. The ocean model is re-entered. The ship roll and pitch cycles are divided into 36 discrete steps and a pattern computed and displayed for each step. The display will be a stop-action type display of antenna pattern vs. time. Entry of 0000 under ISEA will cause this processor to be bypassed.

3. PROCESSOR FUNCTIONAL DESCRIPTION

Figures A-3 thru A-15 are functional flow diagrams of processors. Equations for the ocean model, gain, and input resistance used in the gain and input resistance processors are included in Appendix E. The sources for gain and input resistance equations are ESSA Technical Report ESSA-ERL-110-ITS 78, A.F. Barghausen, J. W. Finney, L. L. Proctor, L. D. Schultz, May 1969 and ESSA Technical Report ESSA-ERL-104-ITS 74, M.T. Ma, L.C. Walters, April 1969. A listing of the Fortran Program used to implement the program is Appendix D.

4. EXTENSION OF THE PROGRAM

The program may be extended to compute patterns for other types of antennas. Adding antennas may be accomplished by inserting an input resistance branch in the input resistance processor and a gain branch in the gain processor. If additional parameters are required, the parameter format must be changed to accept them. Multi-element antennas such as Yagi or Log Periodic will have a mutual impedance matrix; the terms of this matrix may be evaluated using the mutual impedance equations in the dipole

branch. Specific changes required to add antennas to the USNPGS implementation are as follows:

1. Statements 134 and 135 may be changed to new parameter names.

2. After statement 162, add DECODE statements for new parameters.

3. New constants statements, if any, should be inserted between statements 198 and 218.

4. After statement 229 in the input resistance processor, insert IF(ANTN.EQ.9) GO TO 1900.

5. After statement 771 in the input resistance processor, add 1900 INPUT RESISTANCE BRANCH STATEMENTS

```
.
.
.
GO TO 2000
```

6. In the gain processor after statement 272, insert IF(ANTN.EQ.9) GO TO 900.

7. In the gain processor after statement 771, insert 900 ANTENNA GAIN STATEMENTS

```
.
.
.
GO TO 42
```

The dynamic simulation is available for whip, sloping longwire and vertical whip antennas. Simulation of other antennas aboard ship may be made by rewriting gain equations to allow arbitrary orientation of the antenna. Orientation variations are available in the ocean model and the dynamic simulation can then be made.

FIGURE A-1

ANTN

LENG

HGHT

PHIP

THEP

FREQ

EPSL

SGMA

PHI

THET

PARM

ISTH

ISTV

IRCL

HGTT

ALPH

GAIN

ISEA

ICRS

SIGL

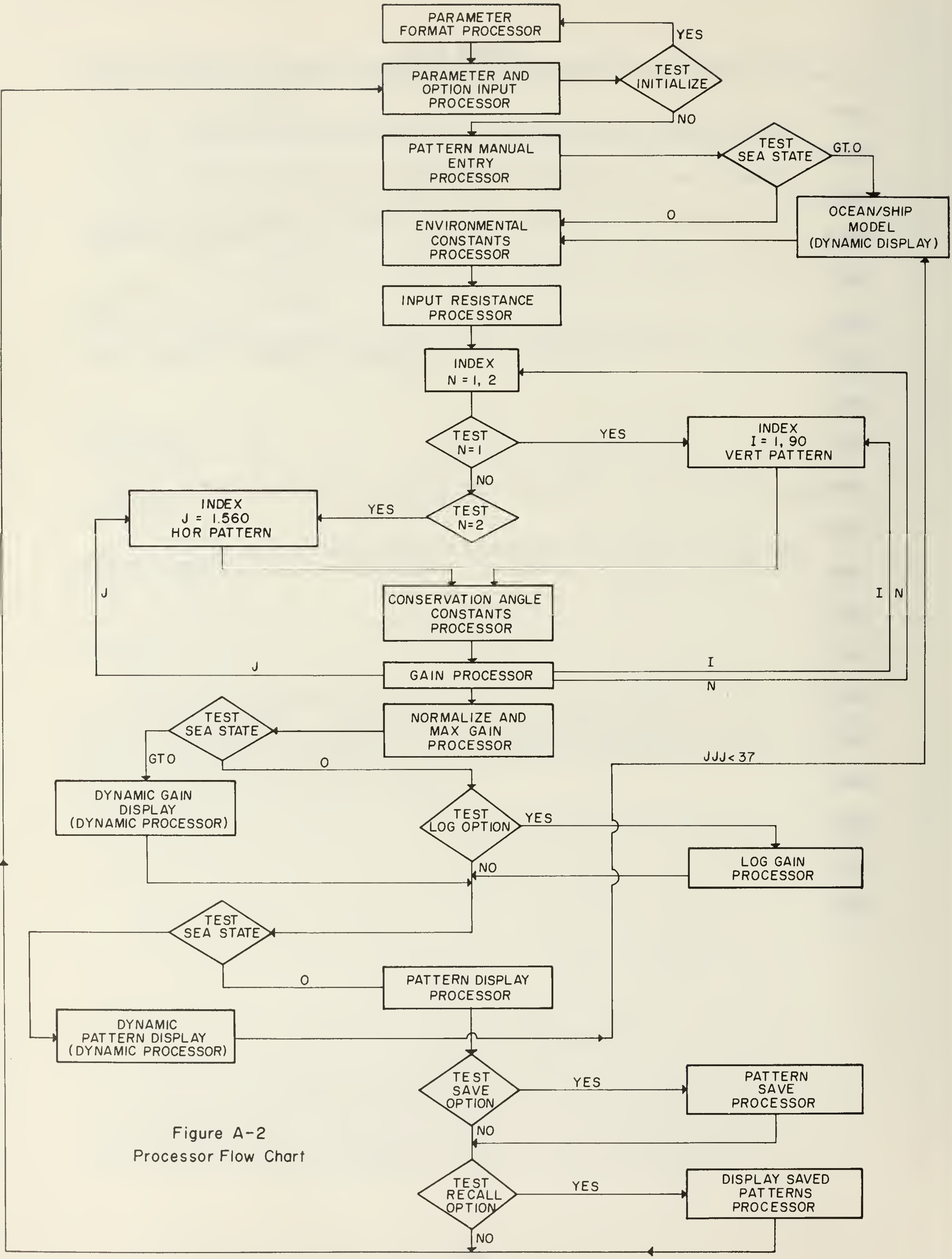


Figure A-2
Processor Flow Chart

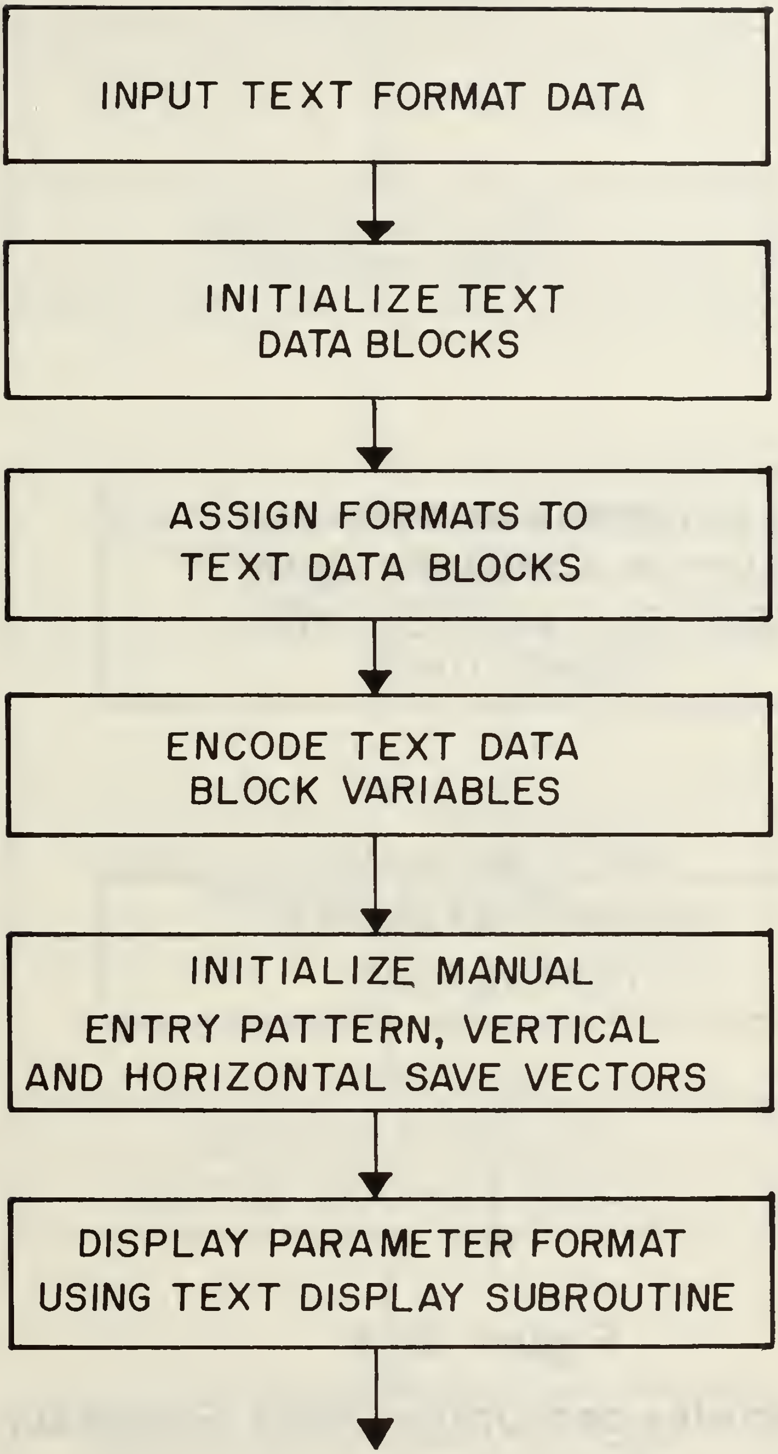


Figure A.3
Parameta Format Processor

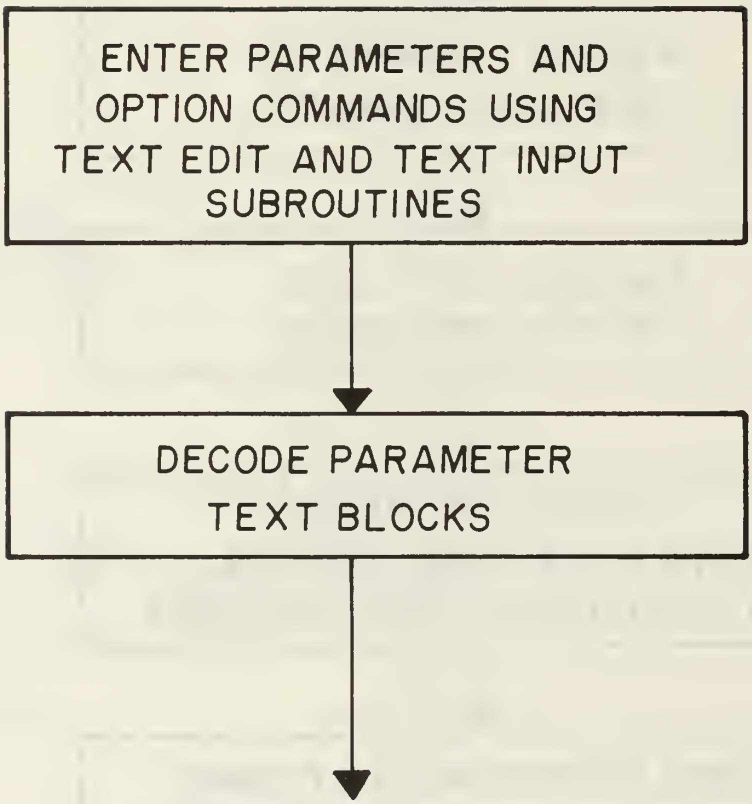


Figure A. 4

Parameter and Option Input Processor

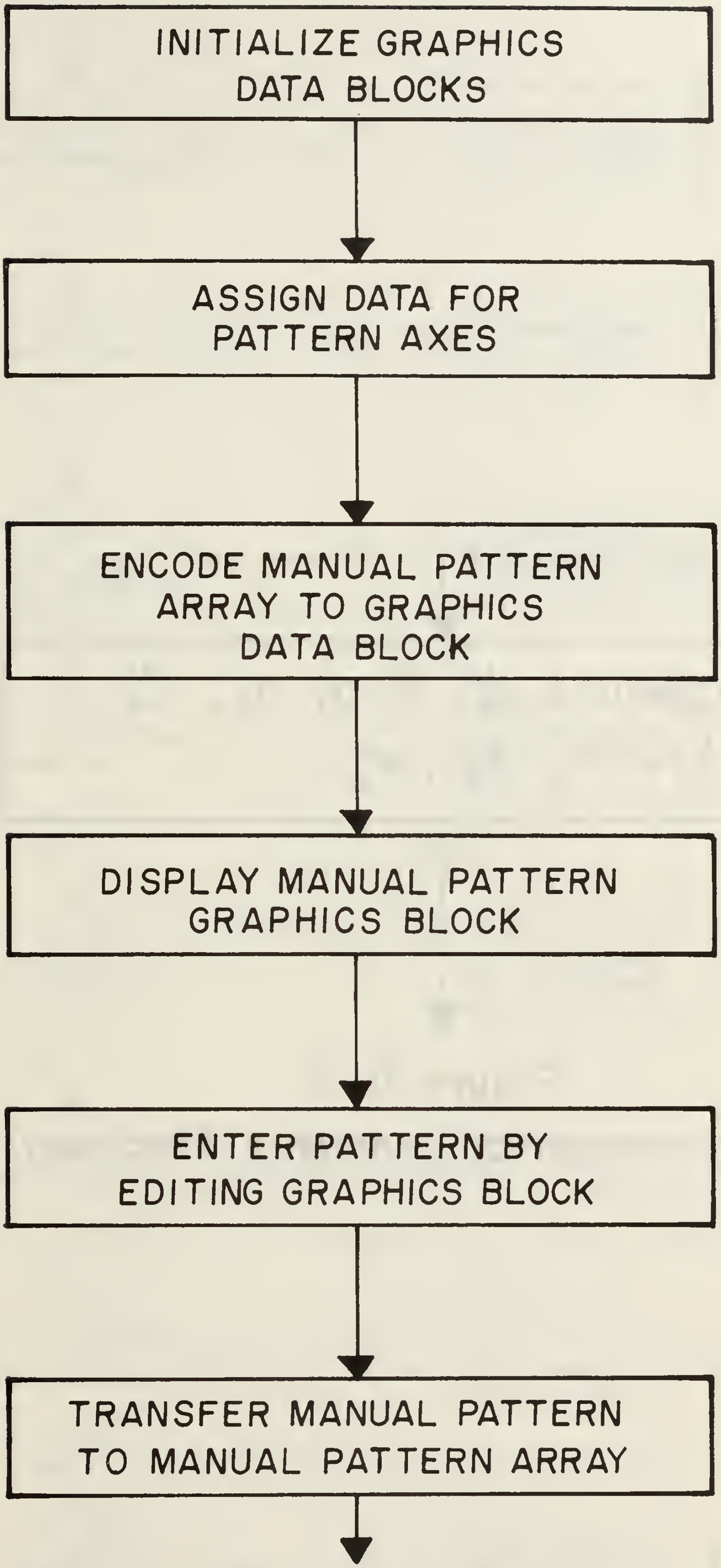


Figure A. 5
Pattern Manual Entry Processor

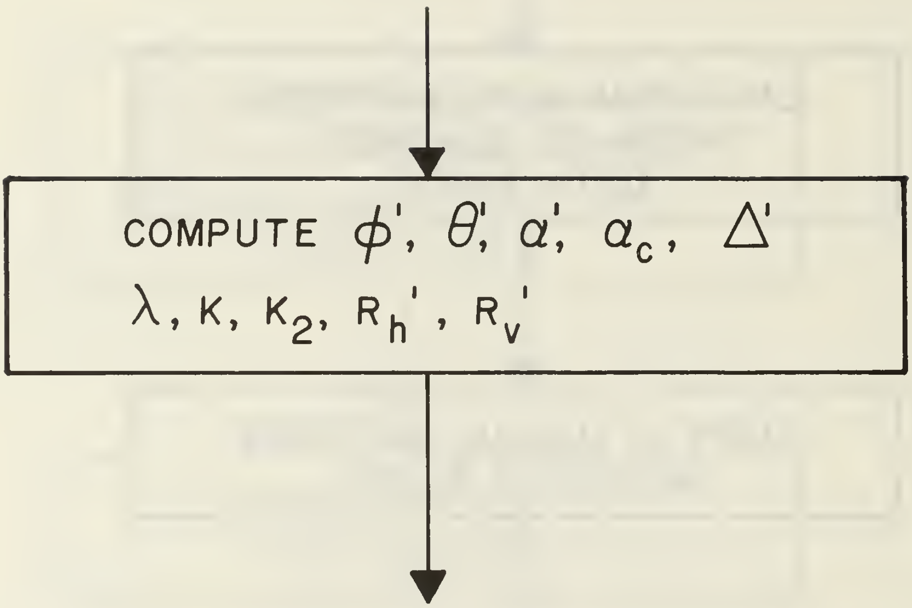


Figure A. 6
Environmental Constants Processor

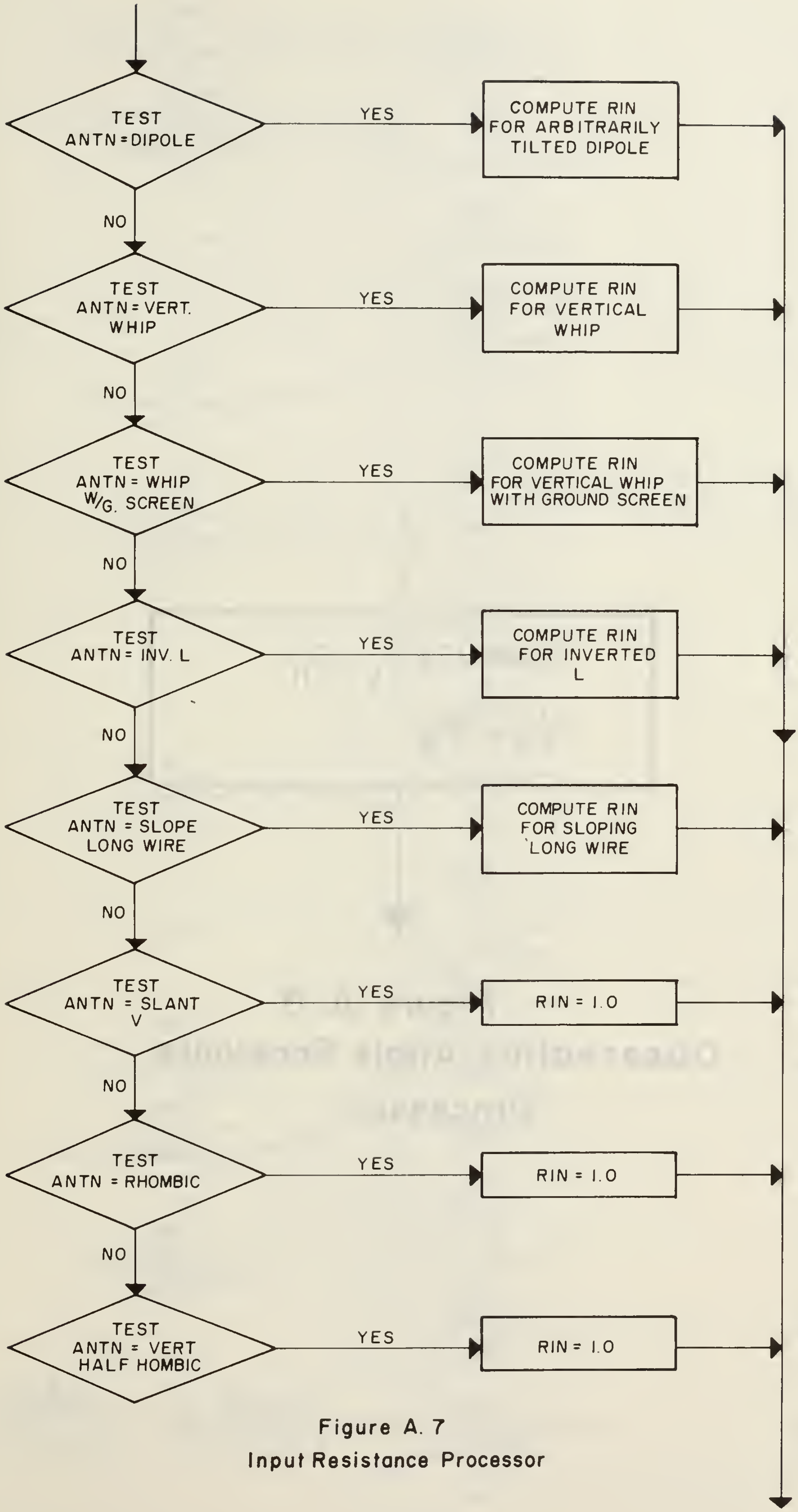


Figure A. 7
Input Resistance Processor

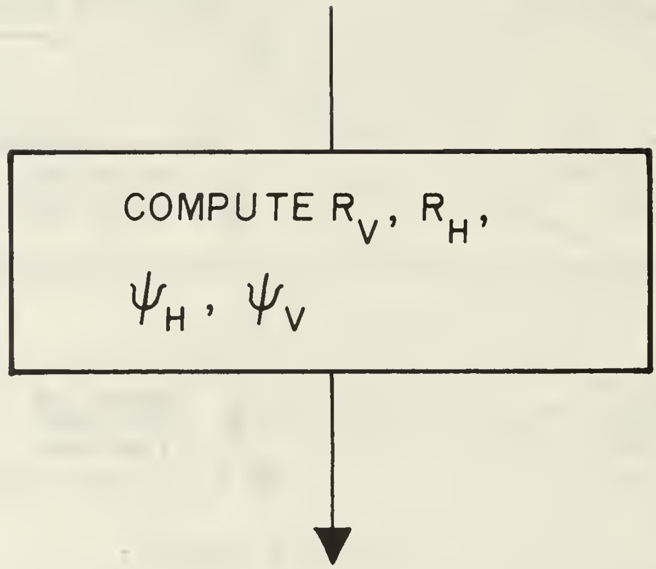


Figure A. 8
Observation Angle Constants
Processor

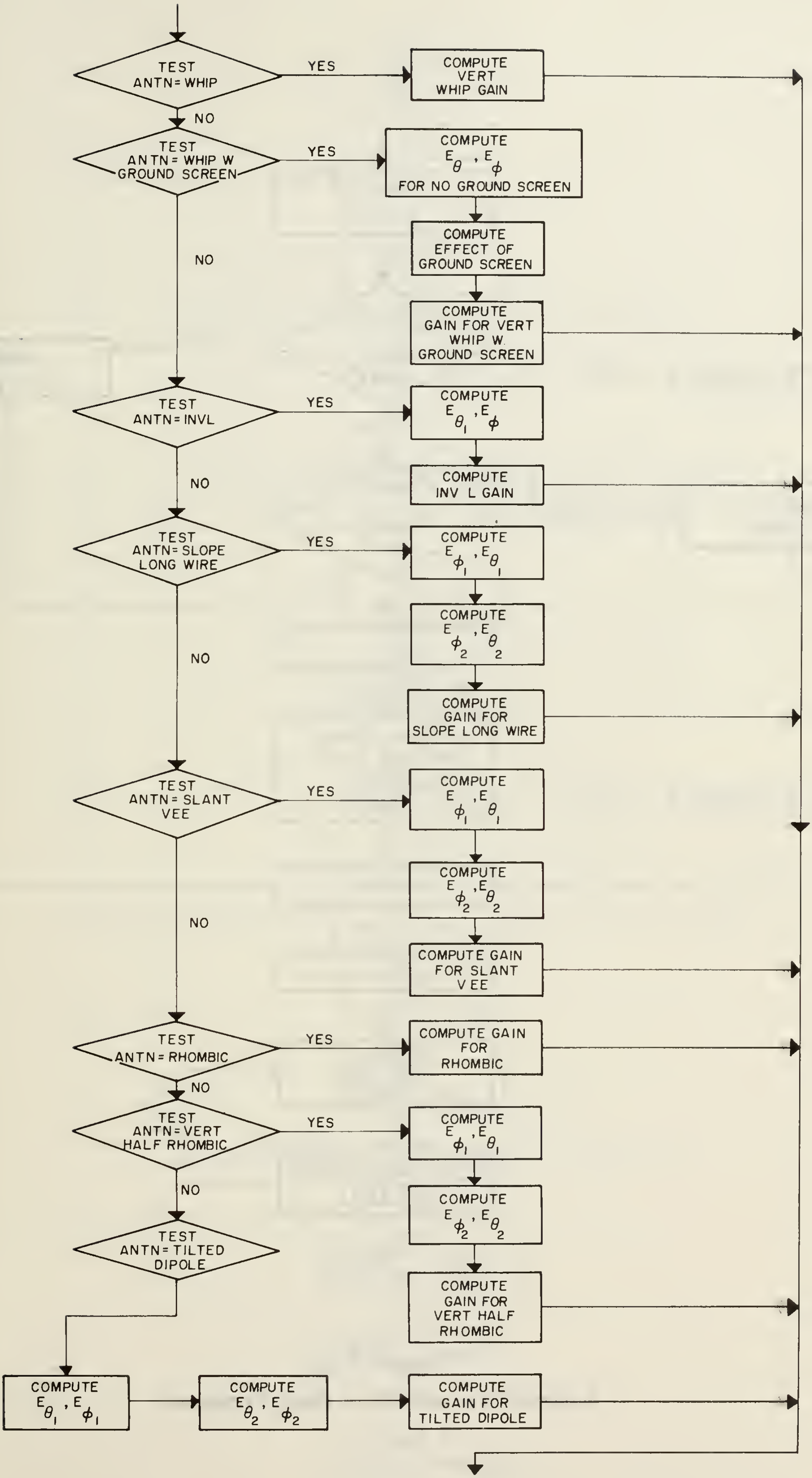


Figure A.9
Gain Processor

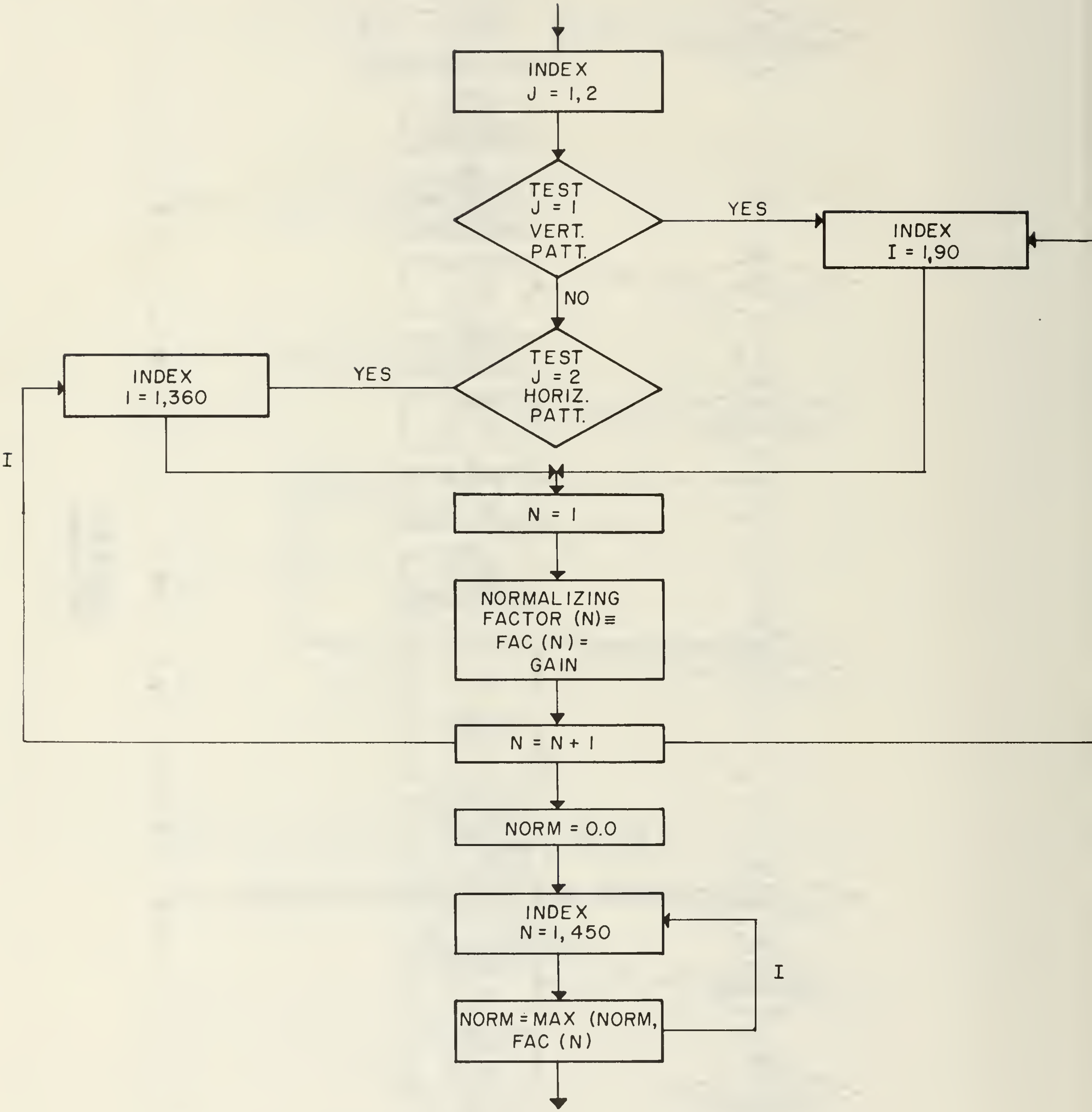


Figure A. 10
Normalize and Max Gain Processor

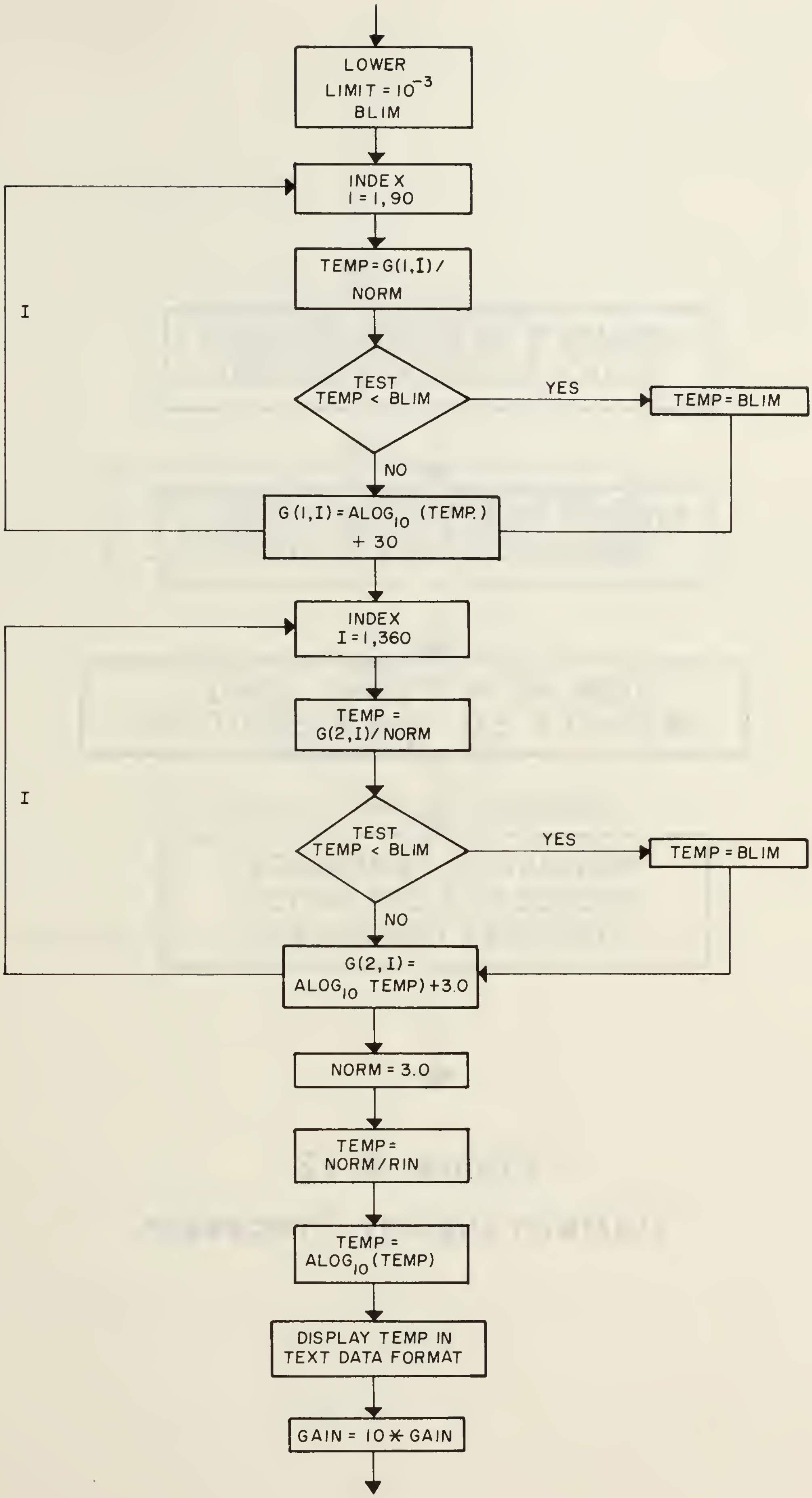


Figure A. 11
Low Gain Processor

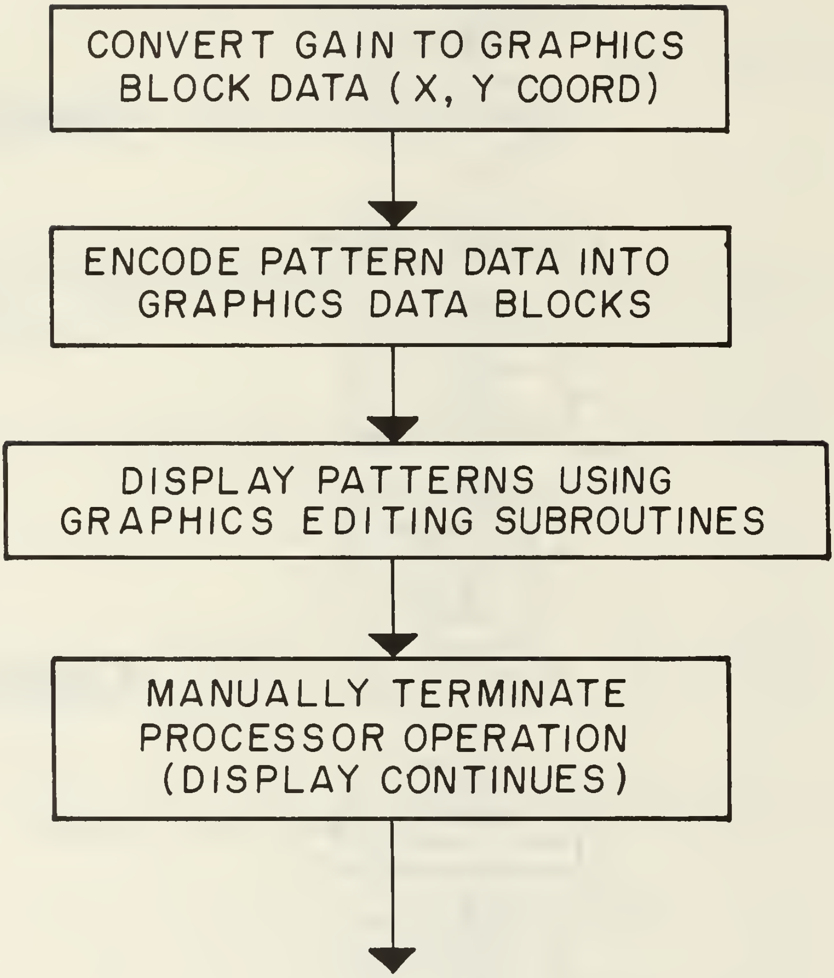


Figure A.12
Pattern Display Processor

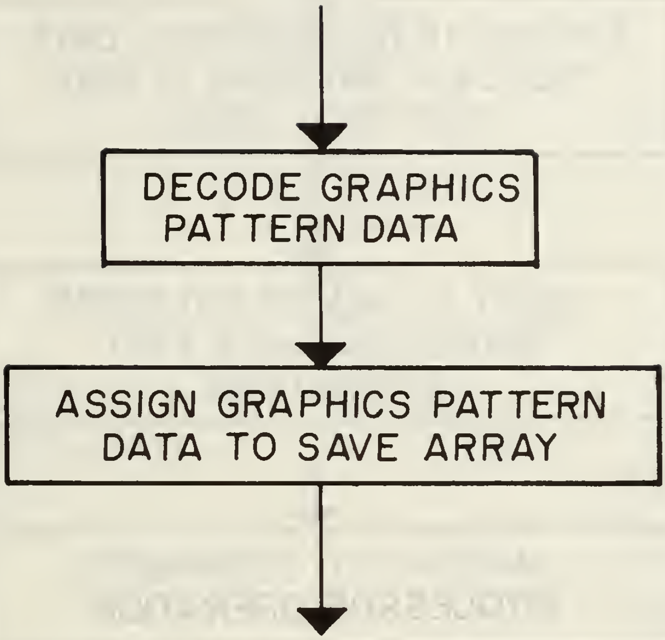


Figure A. 13
Pattern Save Processor

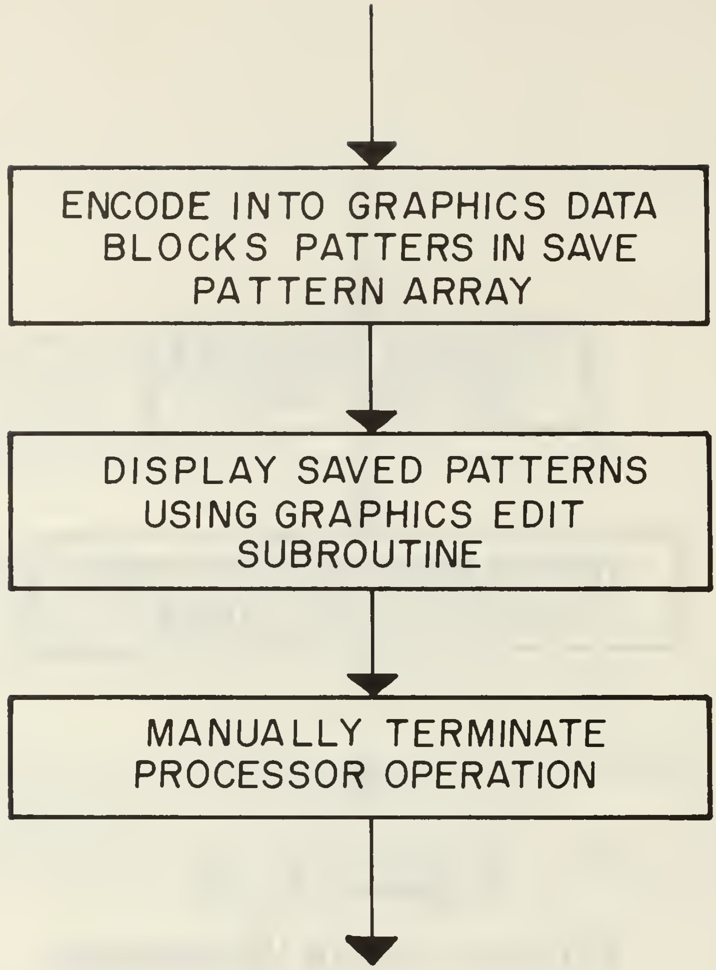


Figure A. 14
Saved Pattern Display Processor

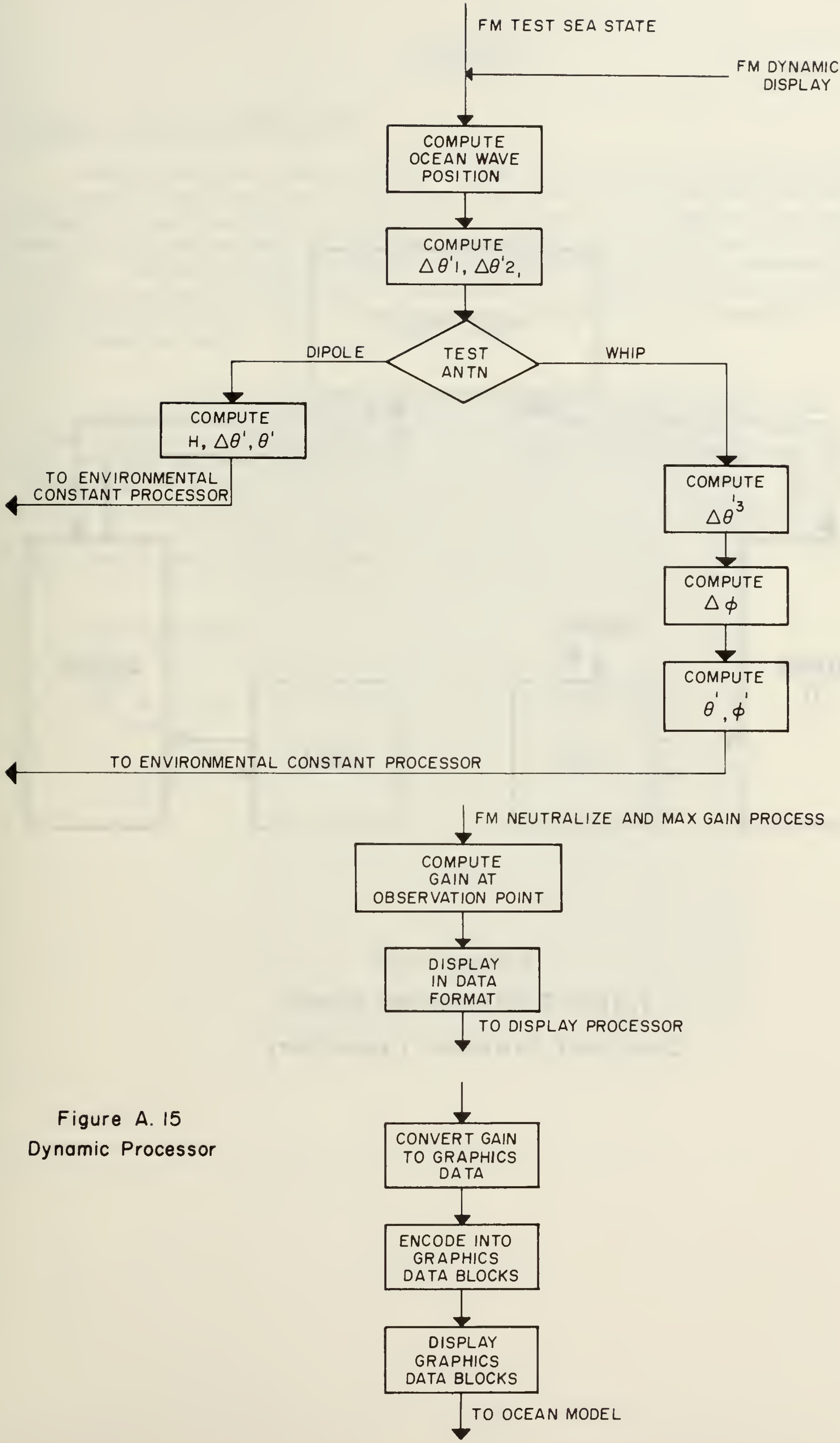


Figure A. 15
Dynamic Processor

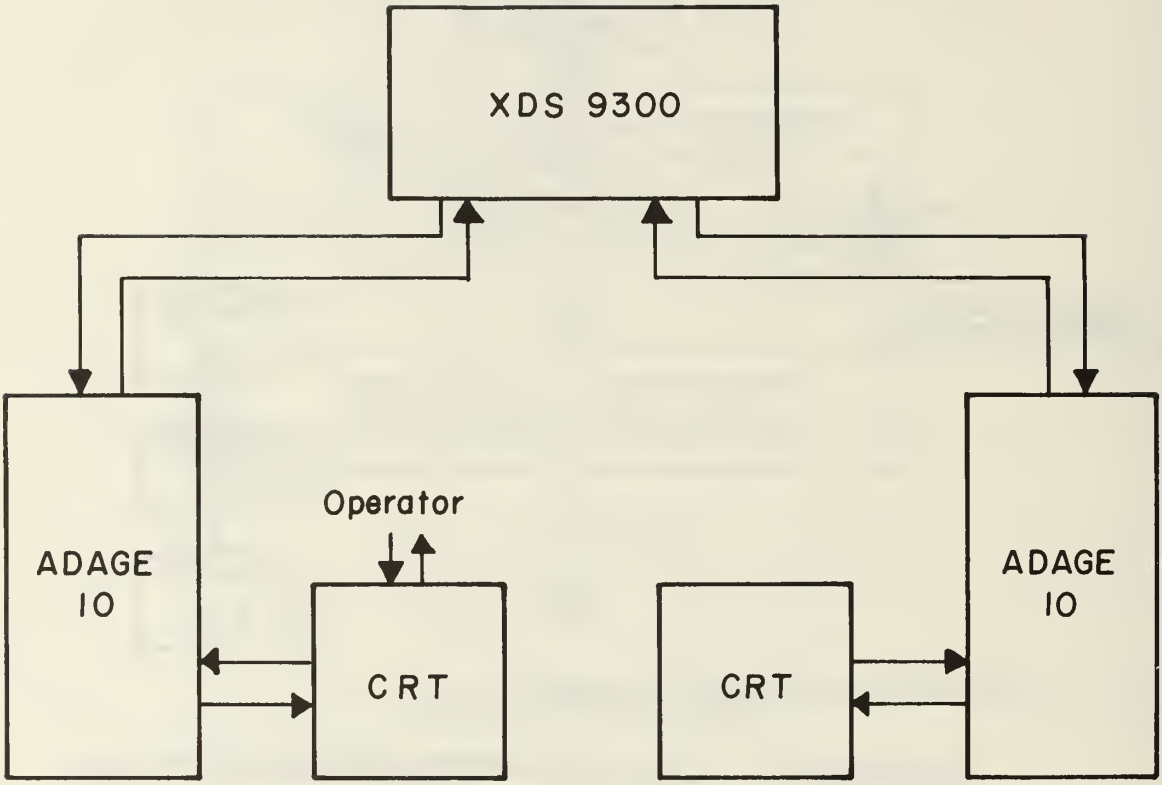


Figure A16
Naval Postgraduate School
Computer Graphics Laboratory

APPENDIX B

EXAMPLE PATTERN COMPUTATIONS

Example pattern calculations for the seven antennas programmed are presented in this section. Patterns were computed for typical parameter values for each antenna. Computation of effects of parameter and environment variations as well as the use of program control options are demonstrated. The text input required to compute each pattern is presented with a CRT photograph of the pattern computed. The USNPGS user may use the text input in conjunction with the user instructions of Appendix F to learn program use.

Figure B-21 is a film strip of the 36 images that comprize the dynamic simulation of a shipboard vertical whip antenna in a state 5 sea from 045 degrees relative to ship's bow. Figure B-22 is a dynamic simulation of a horizontal dipole in the same sea conditions. The images of the dynamic simulation are computed at 10 degree intervals of the ship's roll and pitch period. Figures B-21 and B-22 should be scanned down columns and from bottom of left column to top of right columns.

VERTICAL WHIP

2.Sm
$f = 30.0$ mhz
$\varepsilon_r = 80$

$\delta = 5.00$
$\Theta = 045$
$\phi = 060$

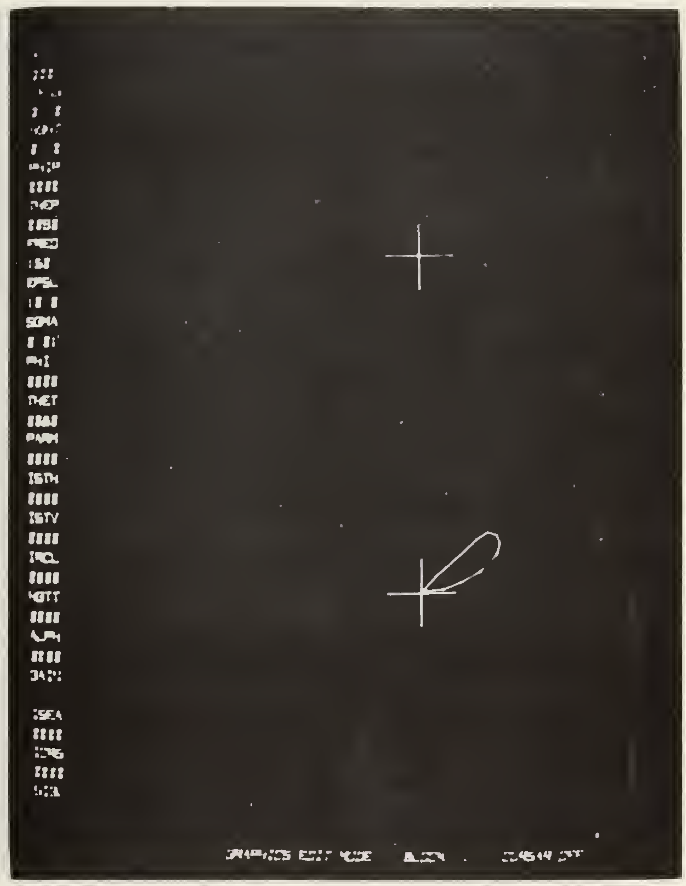
DIPOLE

1.0m
150.0 mhz
$\varepsilon_r = 80$

$\delta = 5.0$
$\Theta = 75^{\circ}$
$\phi = 0$
$h = 6$m

FIGURE B.1

ANTN
0001
LENG
01.0
HGHT
01.0
PHIP
0000
THEP
0090
FREQ
150.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL

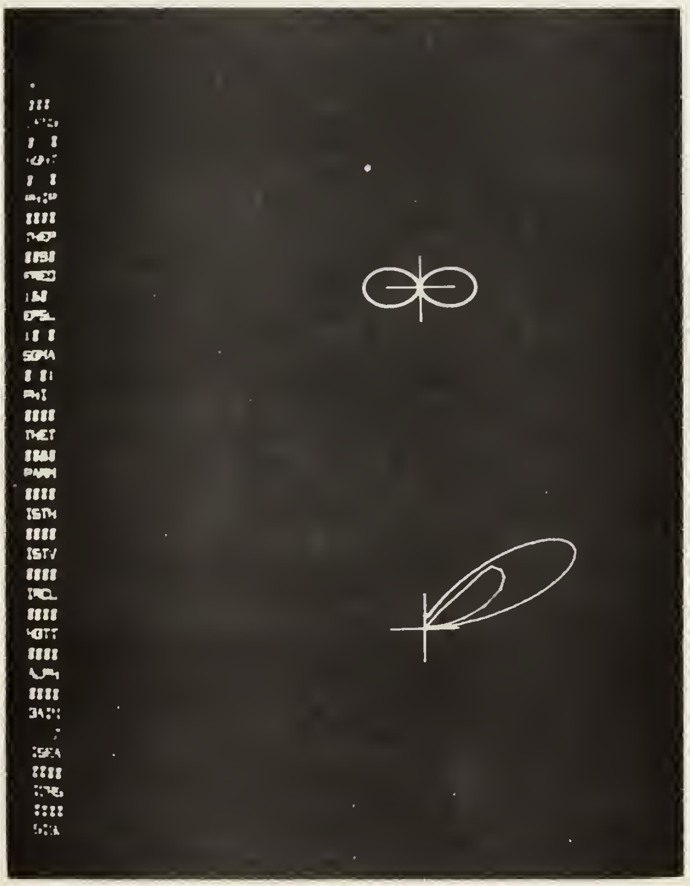


Comments: Manually entered $\lambda/2$

Vertical dipole pattern; height $\lambda/2$

FIGURE B.2

ANTN
0001
LENG
01.0
HGHT
01.0
PHIP
0000
THEP
0090
FREQ
150.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: $\lambda/2$ dipole; $\lambda/2$ height; good ground; $\phi' = 0$, $\theta'=90$, $f=150$ mhz, $\ell=1.0$ $h=1.0$; overlay manually entered pattern;

Observation angles $\phi=0$, $\theta = 80$

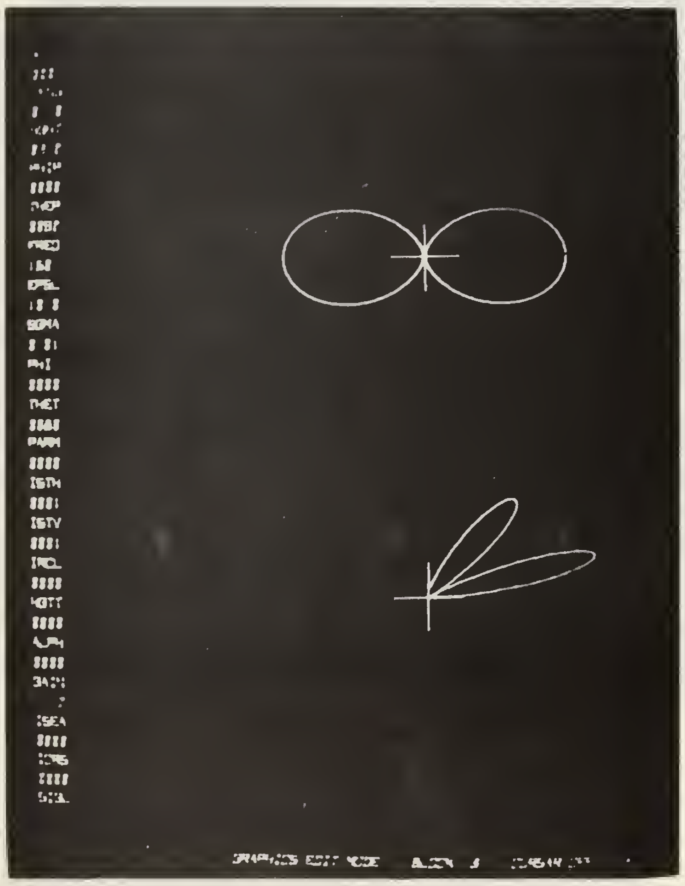
FIGURE B.3

ANTN
0001
LENG
01.0
HGHT
01.0
PHIP
0000
THEP
0090
FREQ
150.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0001
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL

Comments: Erase manual trial pattern
no pattern computed

FIGURE B.4

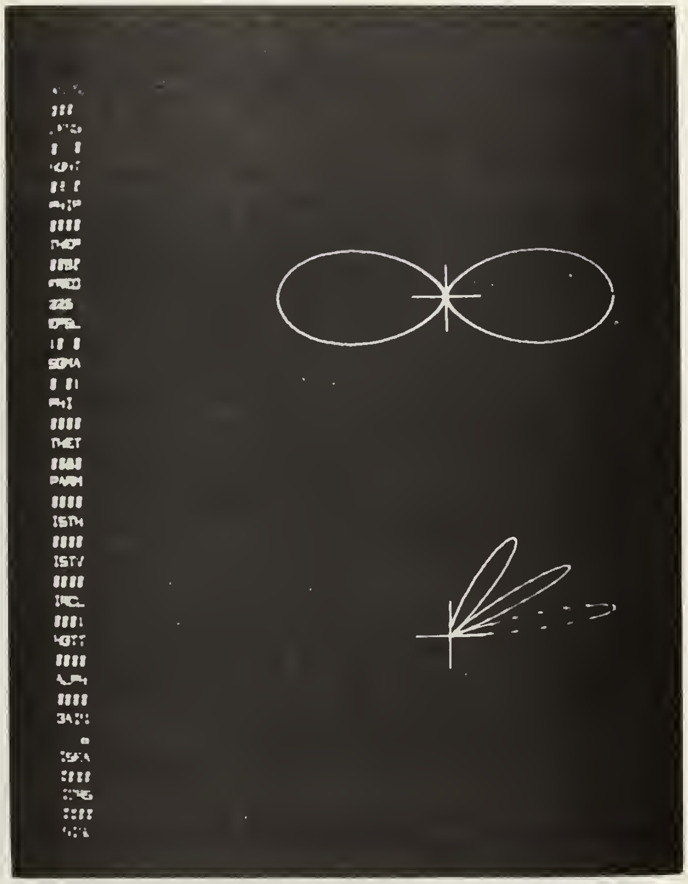
ANTN
0001
LENG
01.0
HGHT
02.0
PHIP
0000
THEP
0090
FREQ
150.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0001
ISTV
0001
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRA
0000
SIGL



Comments: $\lambda/2$ dipole; λ height; good ground; $\phi'=0$, $\Theta'=90$, f= 150 mhz, ℓ= 1.0, h=2.0; Observation angles $\phi=0$, $\Theta=80$; save patterns

FIGURE B.5

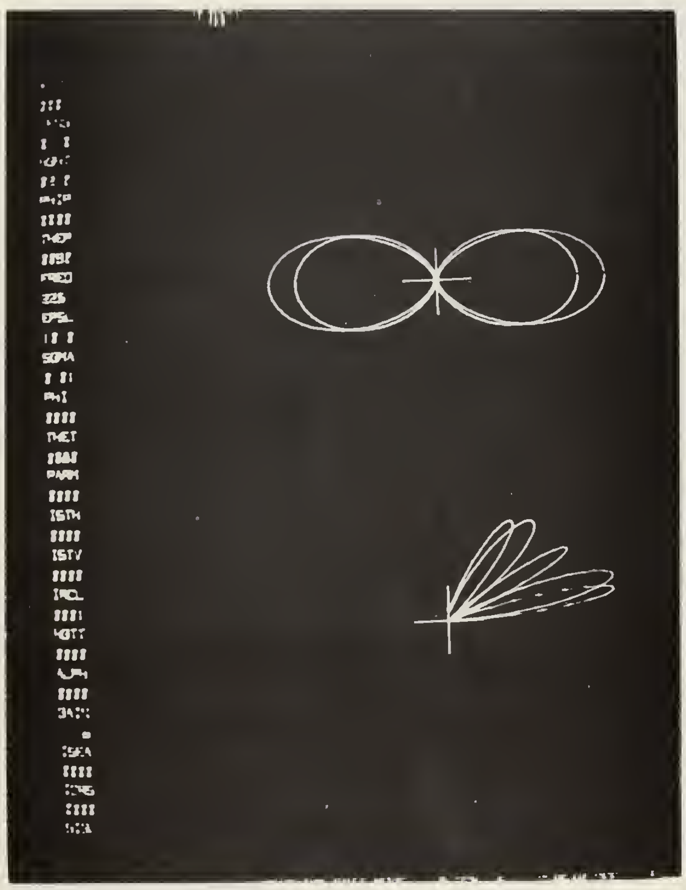
ANTN
0001
LENG
01.0
HGHT
02.0
PHIP
0000
THEP
0090
FREQ
225.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0001
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: 2 $\lambda/3$ dipole; 4 $\lambda/3$ height, good ground, $\phi'=0$, $\Theta'=90$, f=225 mhz, $\ell=1.0$, h=2.0; observation angles, $\phi=0$, $\Theta=80$. The effects of changing frequency are shown here.

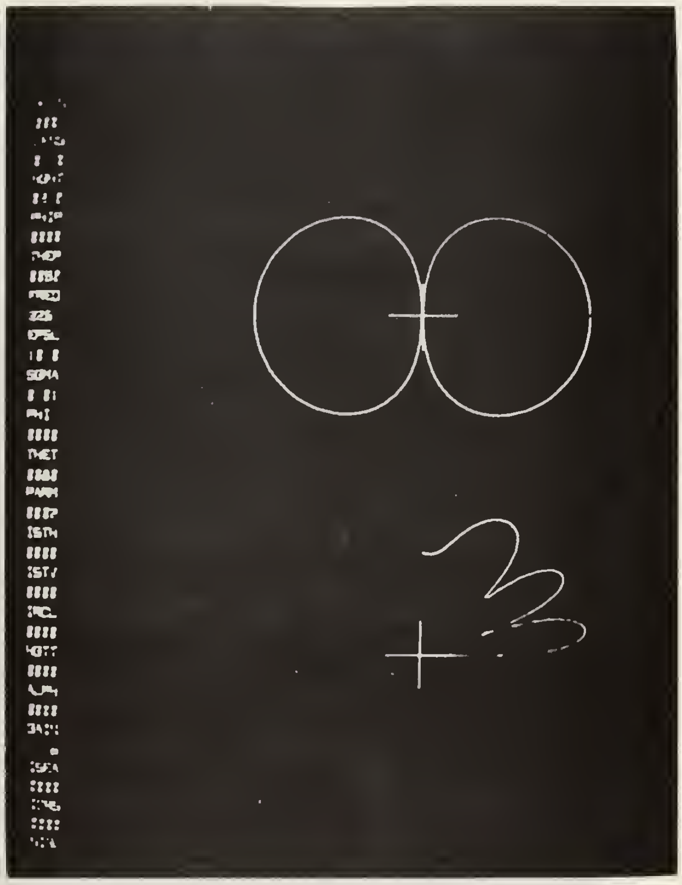
FIGURE B.6

ANTN
0001
LENG
01.0
HGHT
02.0
PHIP
0000
THEP
0090
freq
225.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0001
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Recall pattern 4 and overlay on pattern 5. The use of save and recall options are shown in this example. The options are used to compare the λ dipole (inside and 2 lobe pattern) with 4/3λ dipole (outside and 3 lobe pattern).

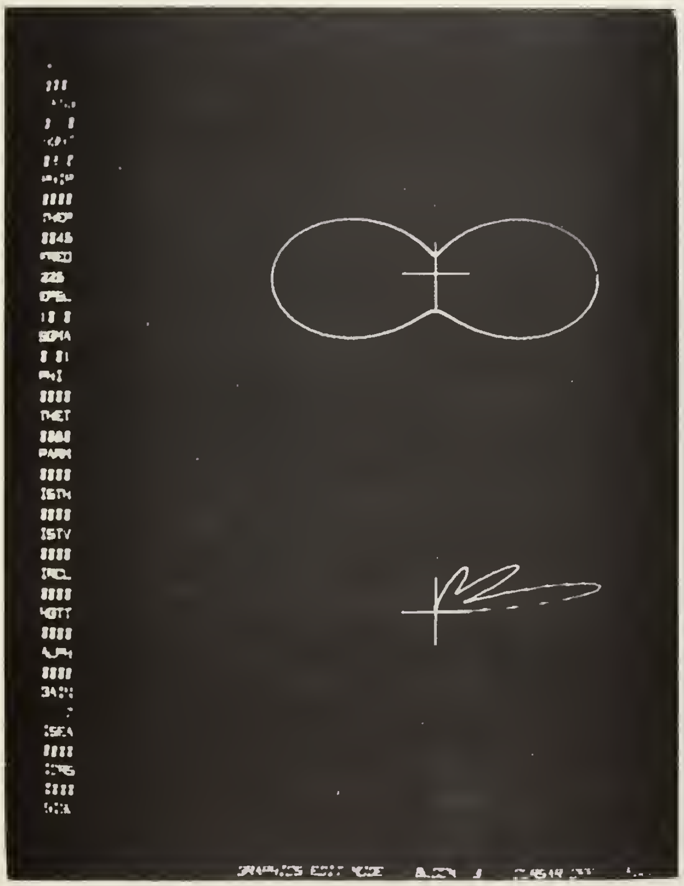
ANTN
0001
LENG
01.0
HGHT
02.0
PHIP
0000
THEP
0090
FREQ
225.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0002
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Two thirds wave length dipole; Four thirds wave length height; good ground, $\phi'=0$, $\Theta'=90$, f=225 mhz, $\ell=1.0$, h=20; observation angles $\phi=0$ $\Theta=80$; Log patterns 30 db scale. Log pattern option is used to study side lobe structure.

FIGURE B.8

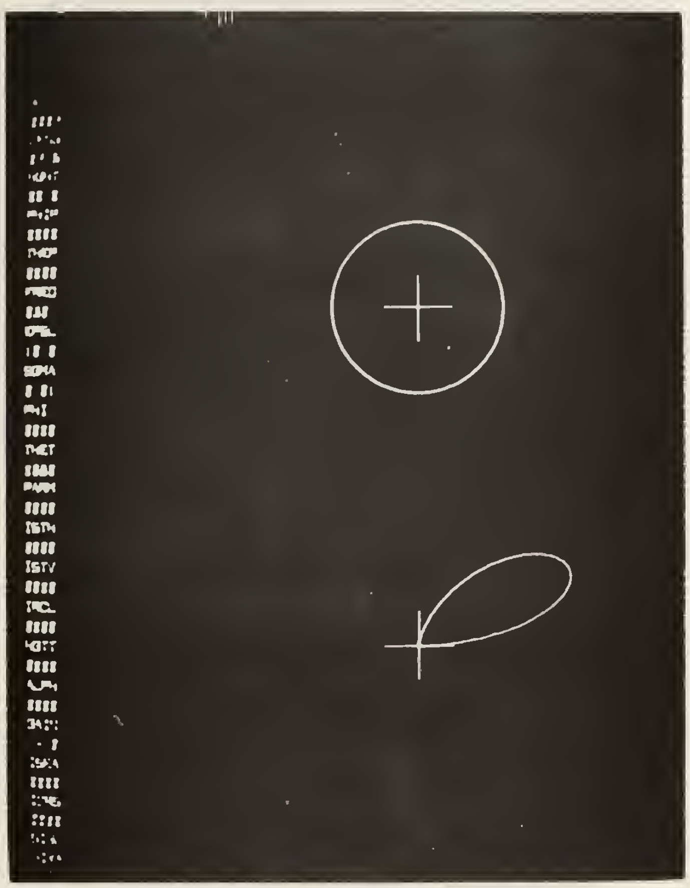
ANTN
0001
LENG
01.0
HGHT
02.0
PHIP
0000
THEP
0045
FREQ
225.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Two thirds wavelength dipole; four thirds wave length height, good ground, $\phi'=0$, $\Theta'=45°$ (tiltangle), f=225 mhz, $\ell=1.0$ h=2.0, observation angles $\phi=0$ $\Theta=80$; Tilted dipole. The effect of tilt on dipole radiation patterns is demonstrated here.

FIGURE B.9

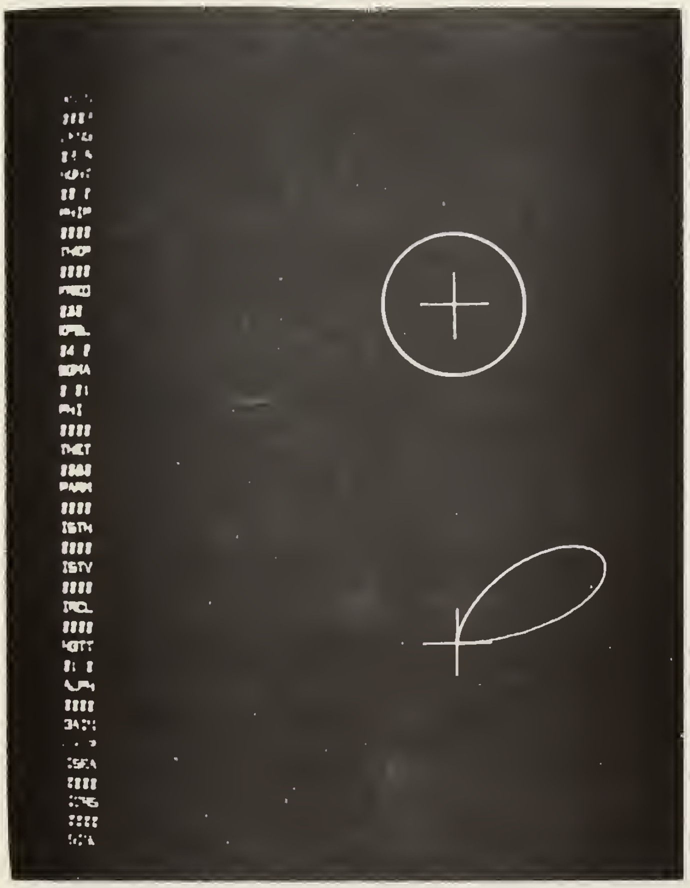
ANTN
0002
LENG
02.5
HGHT
00.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Quarter wavelength whip; good ground, f=30 mhz, ℓ=25; observation angles ϕ=0, Θ=80

FIGURE B.10

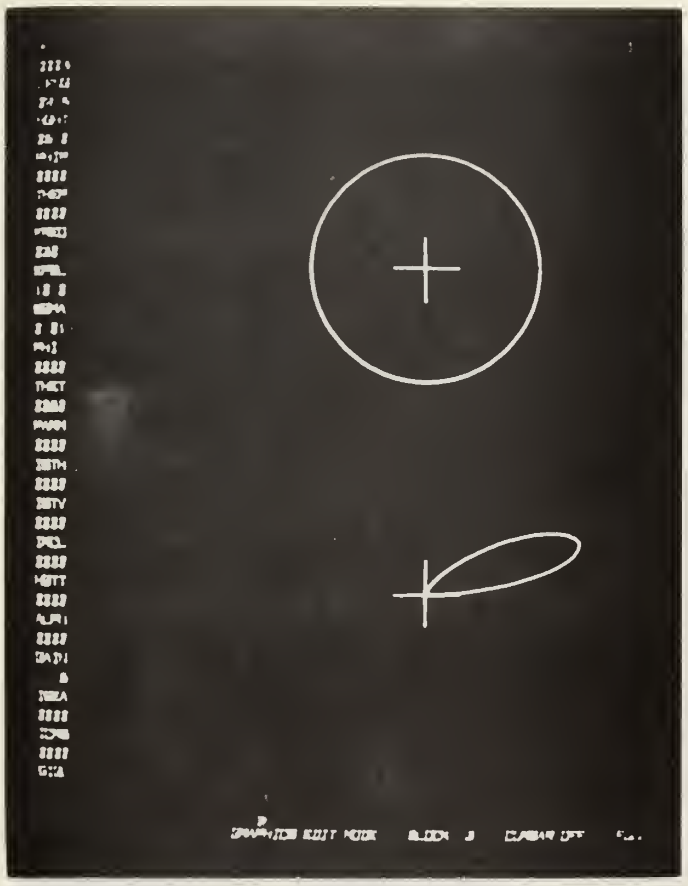
ANTN
0001
LENG
02.5
HGHT
00.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
04.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
01.0
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Quarter wavelength whip; poor ground, f=30 mhz, ℓ= 2.5, observation angles Φ=0, Θ=80. The effects of changes in reflecting ground are shown in this example. The ground change from good ground to poor ground causes a decrease in gain of 2db and a slight increase in Θ of max radiation.

FIGURE B.11

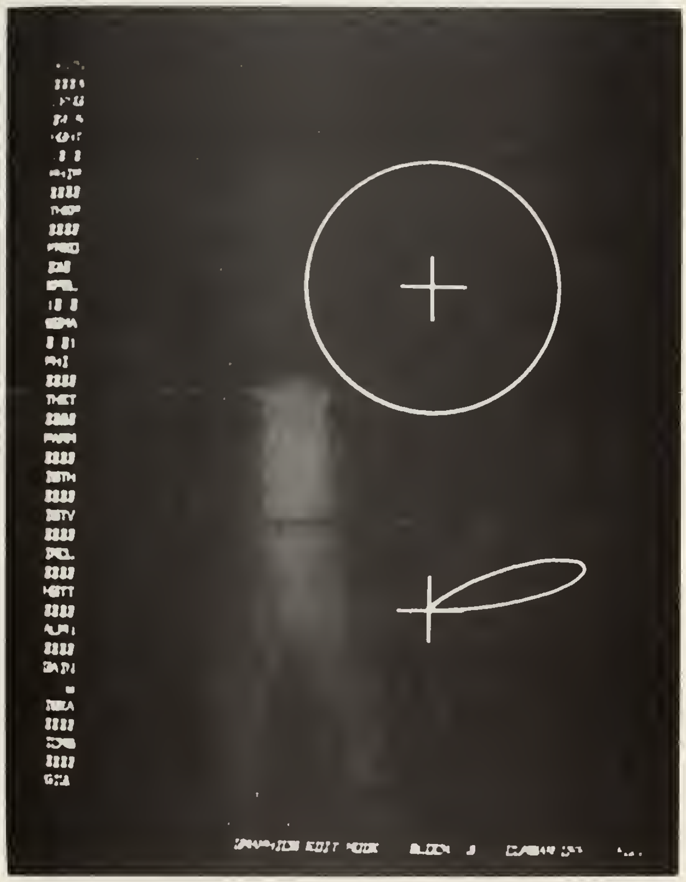
ANTN
0003
LENG
02.5
HGHT
05.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: $\lambda/4$ vertical whip with half wave length ground radial screen.

FIGURE B.12

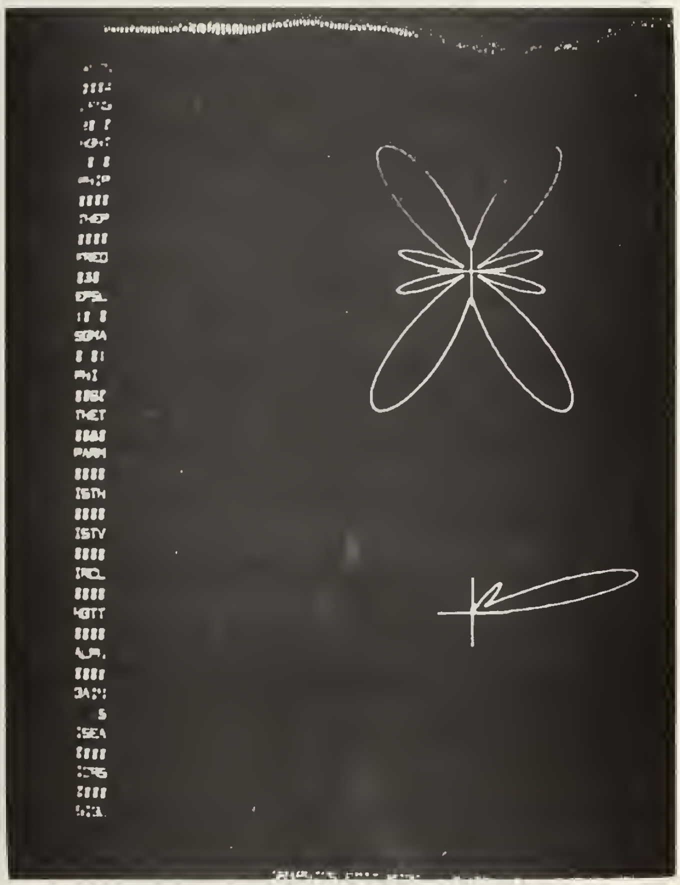
ANTN
0003
LENG
02.5
HGHT
10.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: $\lambda/4$ vertical whip with wave length ground screen. Increasing screen narrows and depresses vertical pattern.

FIGURE B.13

ANTN
0004
LENG
20.0
HGHT
10.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0060
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
SIGL



Comments: Inverted L, horizontal run two wavelengths, vertical run one wavelength; good ground; h=10.0, ℓ=20.0, f=30 mhz; observation angles Φ=60, Θ=80.

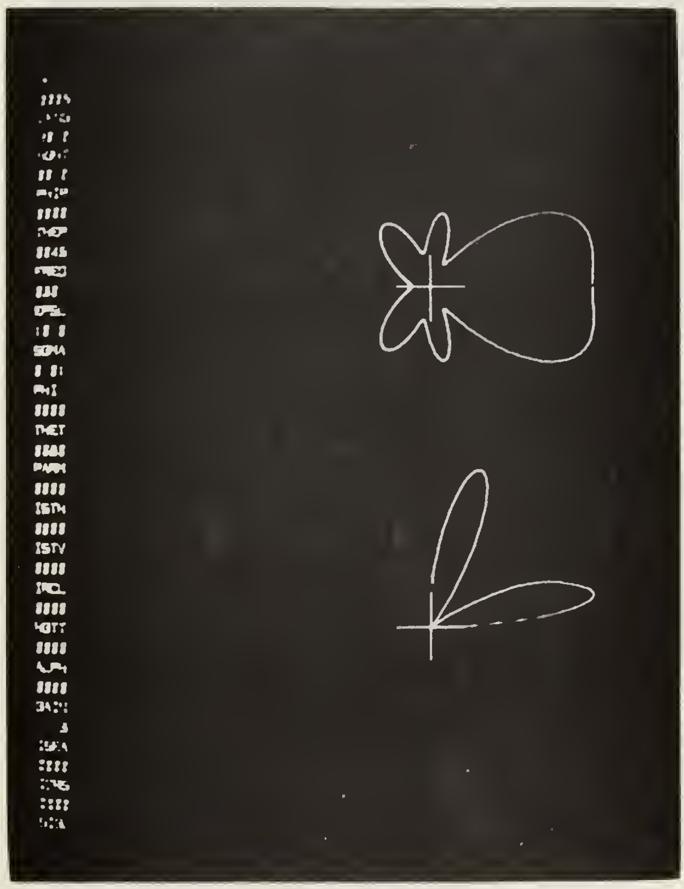
FIGURE B.14

ANTN
0004
LENG
20.0
HGHT
05.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0090
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL

Comments: Inverted L, horizontal run two wavelengths, vertical run one-half wave lenth; good ground; h=5.0, ℓ=20.0, f=30 mhz; observation angles Φ=90, Θ=80. The effects of change in vertical run length are shown here.

FIGURE B.15

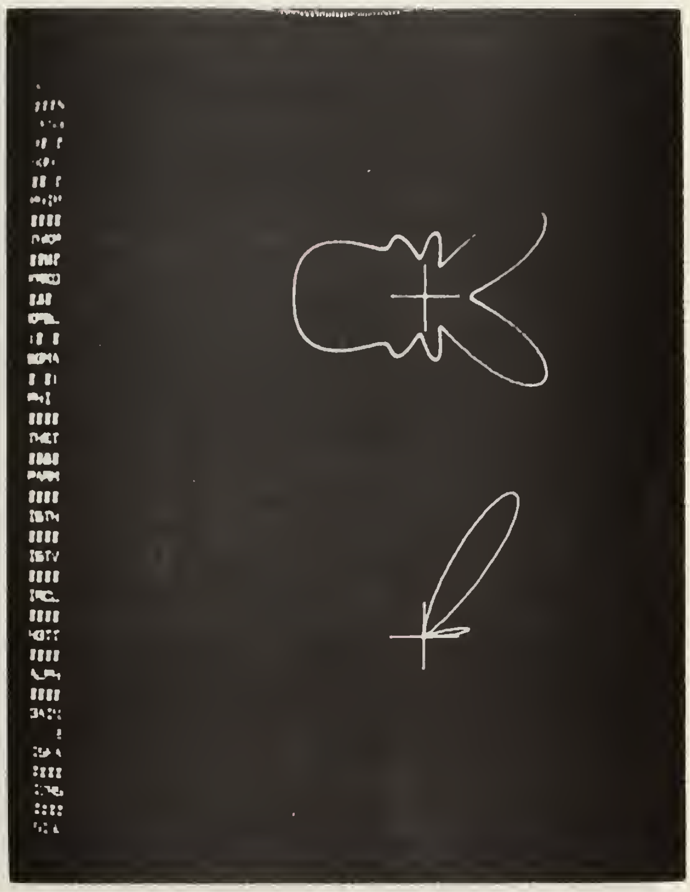
ANTN
0005
LENG
20.0
HGHT
00.0
PHIP
0000
THEP
0045
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Sloping Long wire; two wavelengths; good ground; $\Phi=0$, $\Theta'=45°$, $\ell=20$, $f=30$ mhz, observation angles $\Phi=0$, $\Theta=80$.

FIGURE B.16

ANTN
0005
LENG
20.0
HGHT
00.0
PHIP
0000
THEP
0060
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0000
GAIN
ISEA
0000
ICRS
SIGL



Comments: Sloping Longwire; two wavelengths; good ground; $\Phi'=0$, $\Theta'=60$, $\ell=20.0$, f=30 mhz; observation angles $\Phi=0$, $\Theta=80$. This set of two examples demonstrates the effect of variation of tilt angle on radiation patterns.

FIGURE B.17

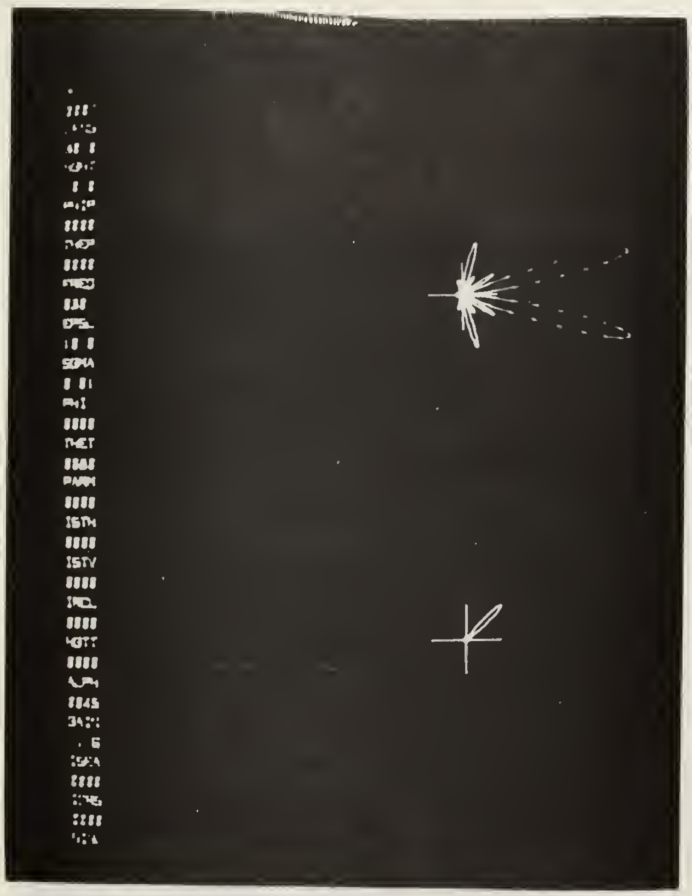
ANTN
0007
LENG
30.0
HGHT
10.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0030
GAIN
ISEA
0000
ICRS
0000
SIGL

Comments: Horizontal rhombic; three wavelength sides; good ground; one wavelength height; ℓ=30.0, h=10.0, α=30°, f=30 mhz; observation angles Φ=0, Θ=80.

FIGURE B.18

ANTN
0007
LENG
30.0
HGHT
10.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0045
GAIN

ISEA
0000
ICRS
0000
SIGL



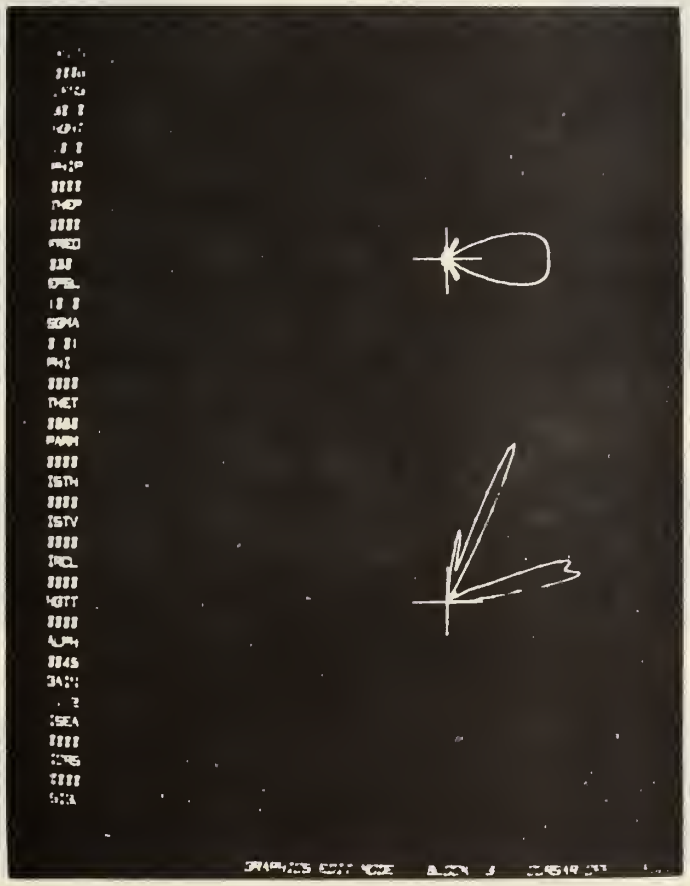
Comments: Horizontal rhombic, three wavelength sides; good ground, one wavelength height; $\ell=30.0$, $h=10.0$ $\alpha=45°$, $f=30$ mhz; observation angles $\Phi=0$, $\Theta=80$. These last two computations show clearly how the program may be used to synthesize antenna systems. A non-optimum α is compared to the optimum for a given h,ℓ etc. Since this antenna is fairly difficult to build, the use of the program to synthesize the optimum is well justified.

ANTN
0008
LENG
30.0
HGHT
10.0
PHIP
0000
THEP
0000
FREQ
050.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0030
GAIN
ISEA
0000
ICRS
0000
SIGL

Comments: Vertical half rhombic, three wavelength sides, good ground, ℓ=30.0, α=30°, f=30mhz; observation angles Φ=0, Θ=80. This antenna has a major lobe at approximately 40° elevation and may be suited for propagation conditions requiring high elevation lobes.

FIGURE B.20

ANTN
0008
LENG
30.0
HGHT
10.0
PHIP
0000
THEP
0000
FREQ
030.
EPSL
10.0
SGMA
0.01
PHI
0000
THET
0080
PARM
0000
ISTH
0000
ISTV
0000
IRCL
0000
HGTT
0000
ALPH
0045
GAIN
ISEA
0000
ICRS
0000
SIGL



Comments: Vertical half rhombic, three wavelength aides, good ground, $\ell=30.0$, $\alpha=45°$, $f=30$ mhz; observation angles $\phi=0$, $\Theta=80$. Increasing α splits the energy into a high and low lobe and decreases gain from the previous case.

Vertical Whip Pattern Small Ship
Sea State 5 from 045°R

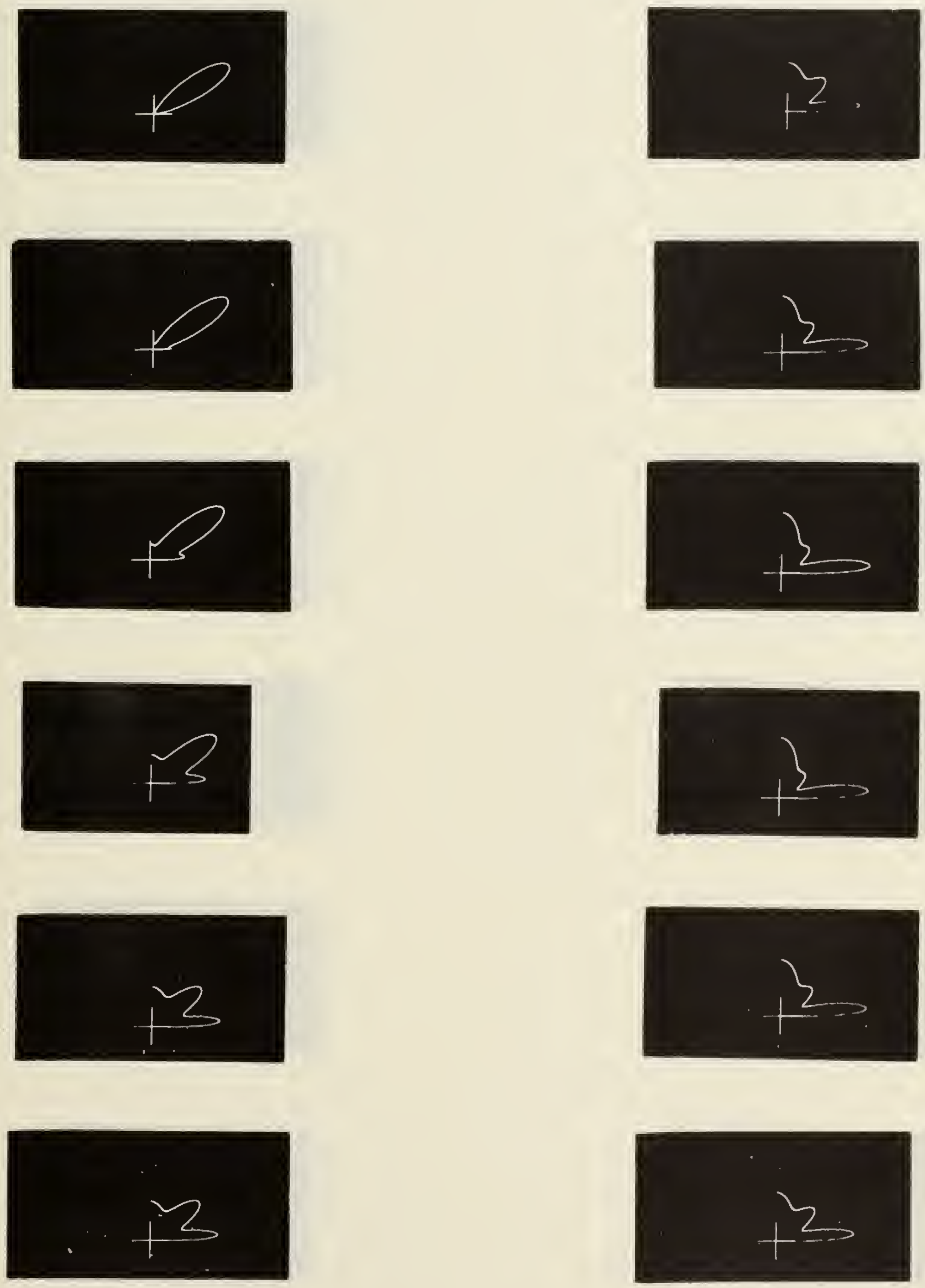


Figure B-21

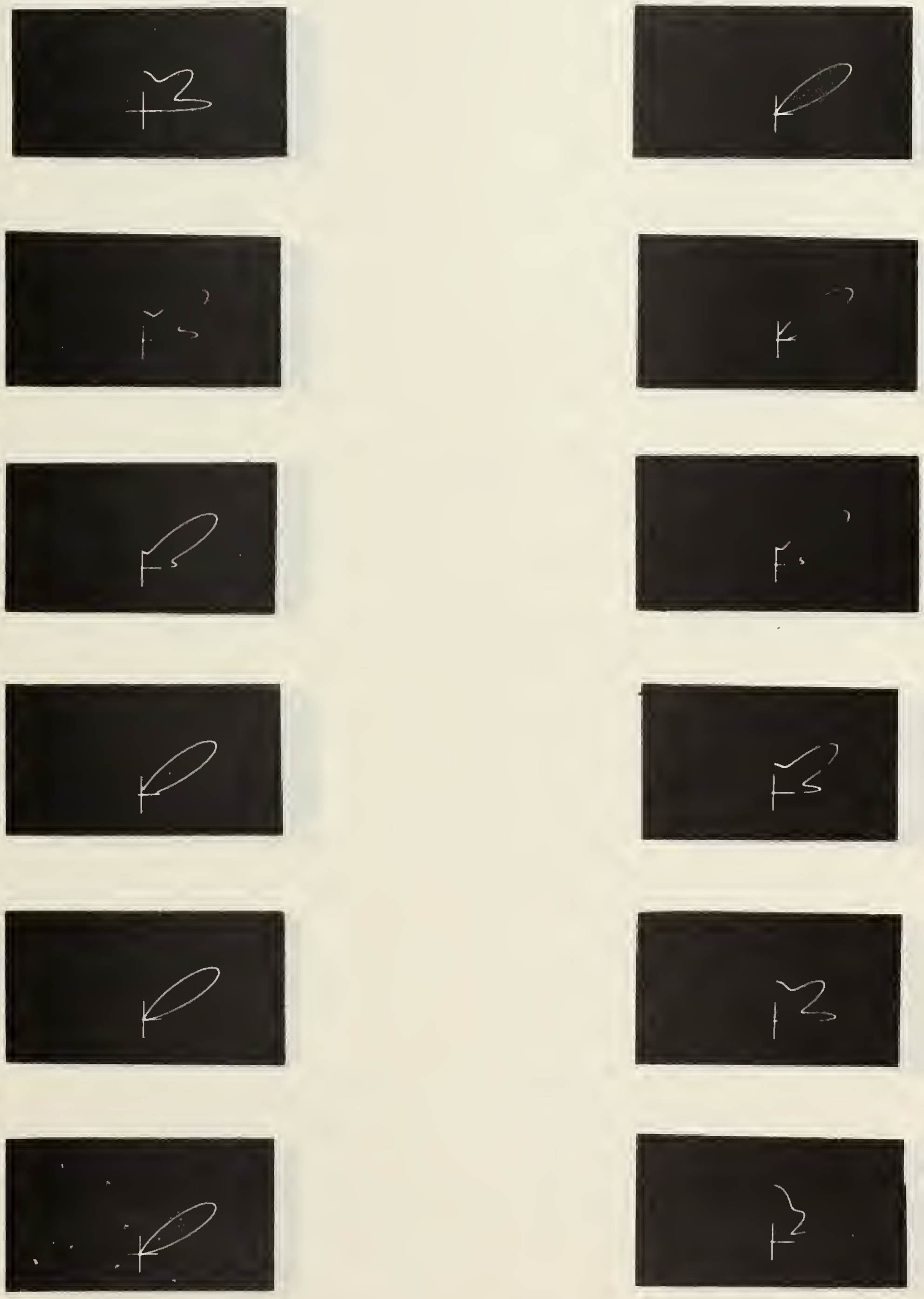


Figure B-21

Figure B-21

Vertical Whip
Horizontal Pattern

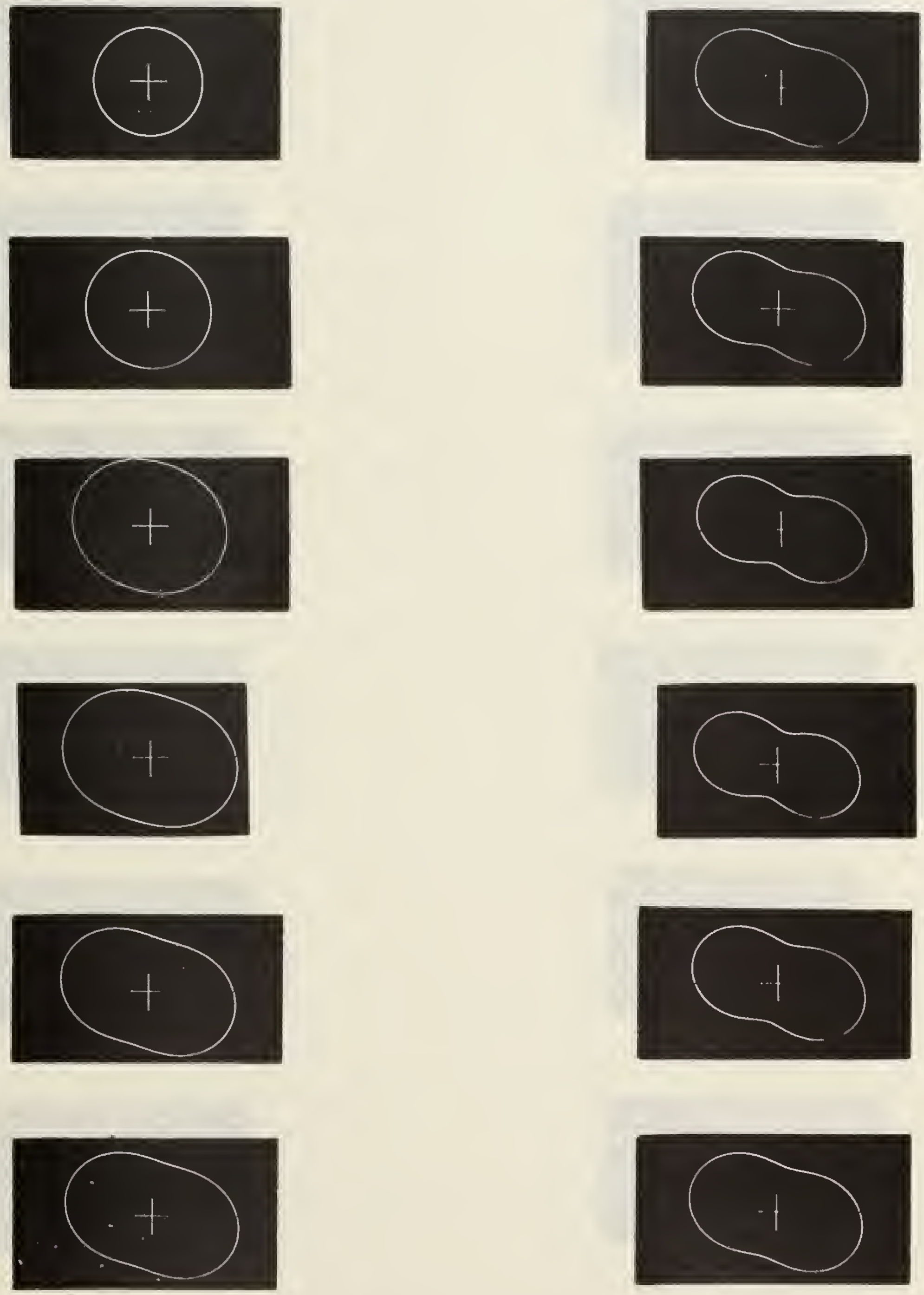


Figure B-21

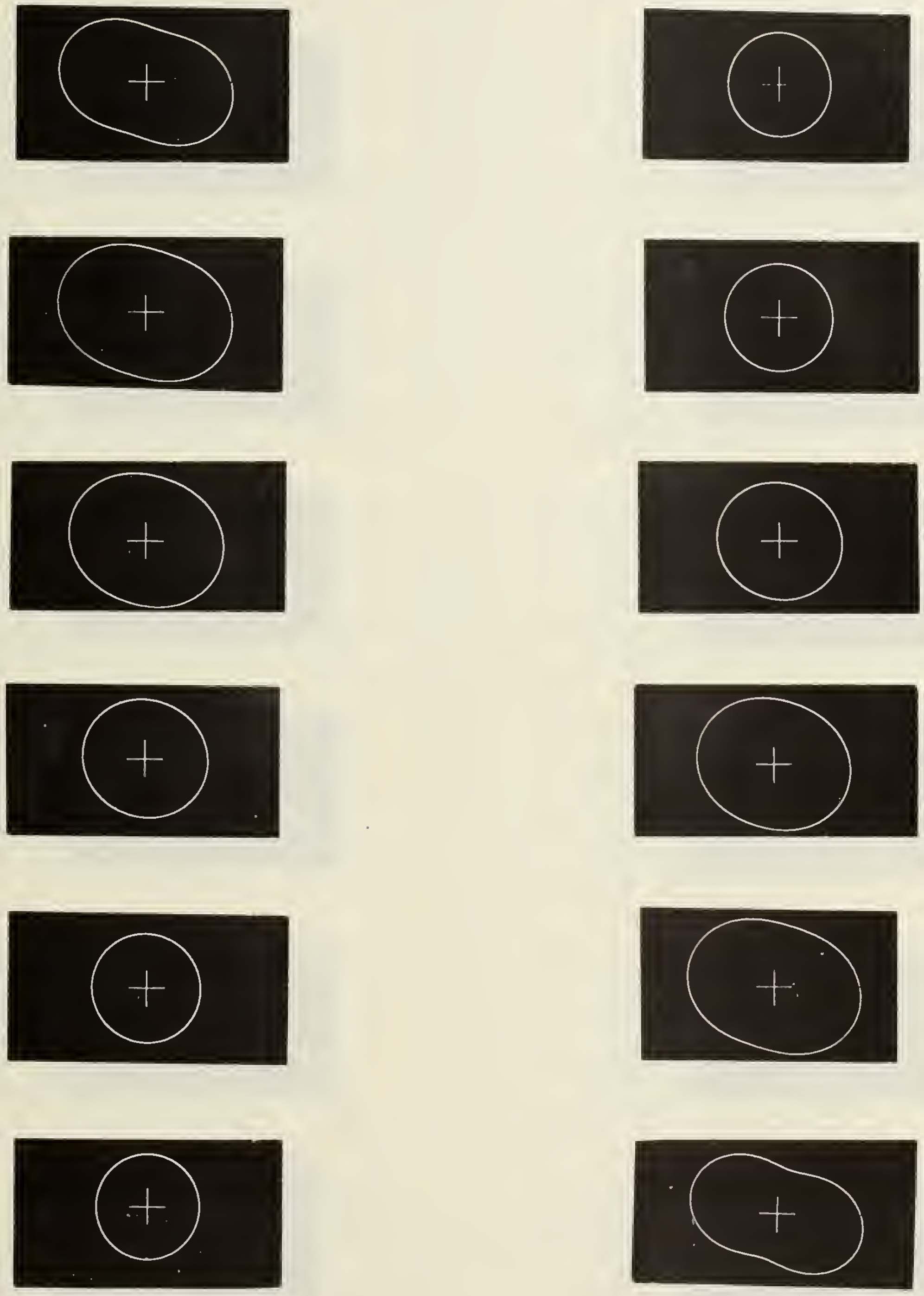


Figure B-21

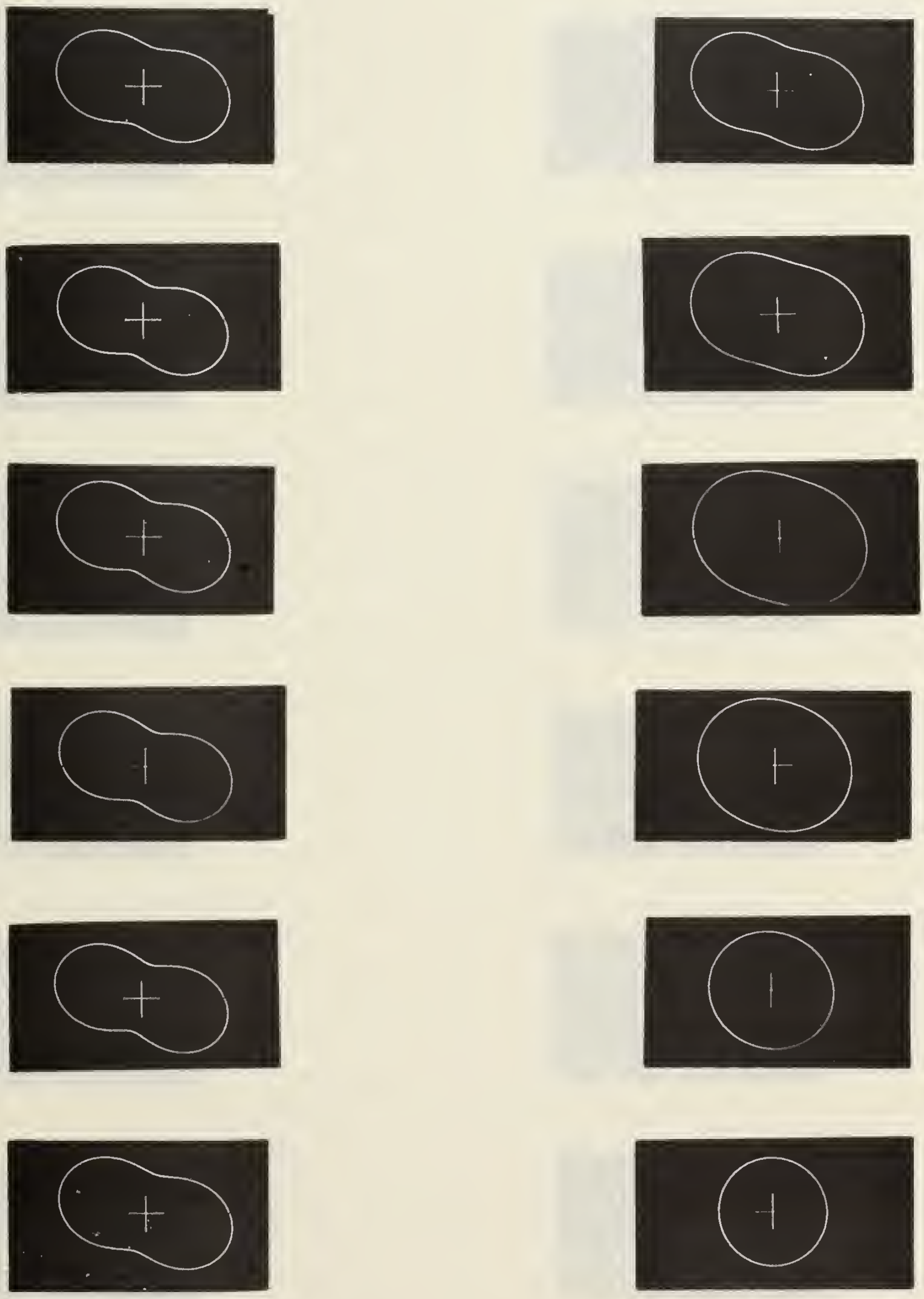


Figure B-21

Half Wave Dipole
Vertical Pattern

Small Ship
Sea State 5 from 045°R

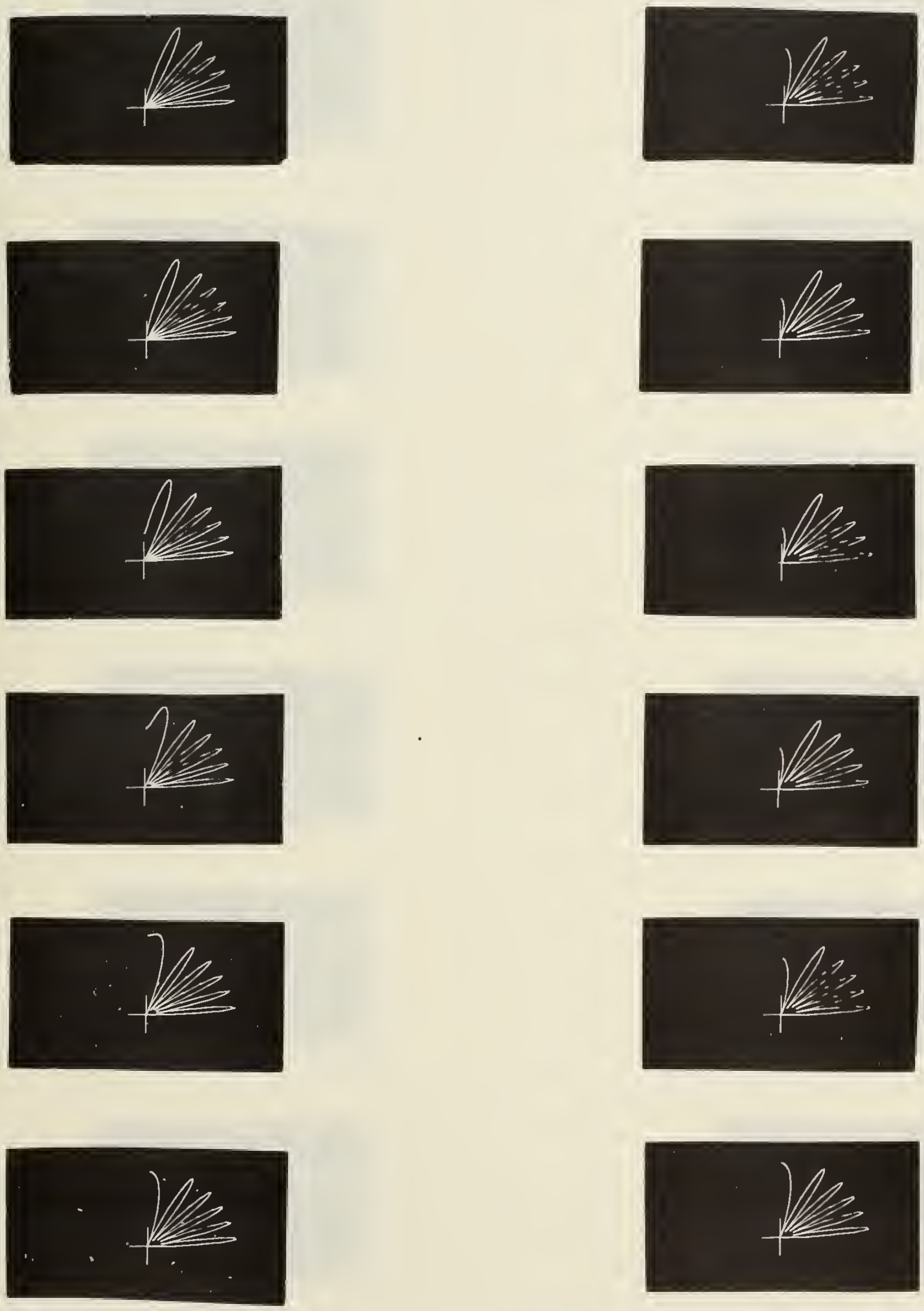


Figure B-22

Figure B-22

Figure B-22

Figure B-22

Half Wave Dipole
Horizontal Pattern

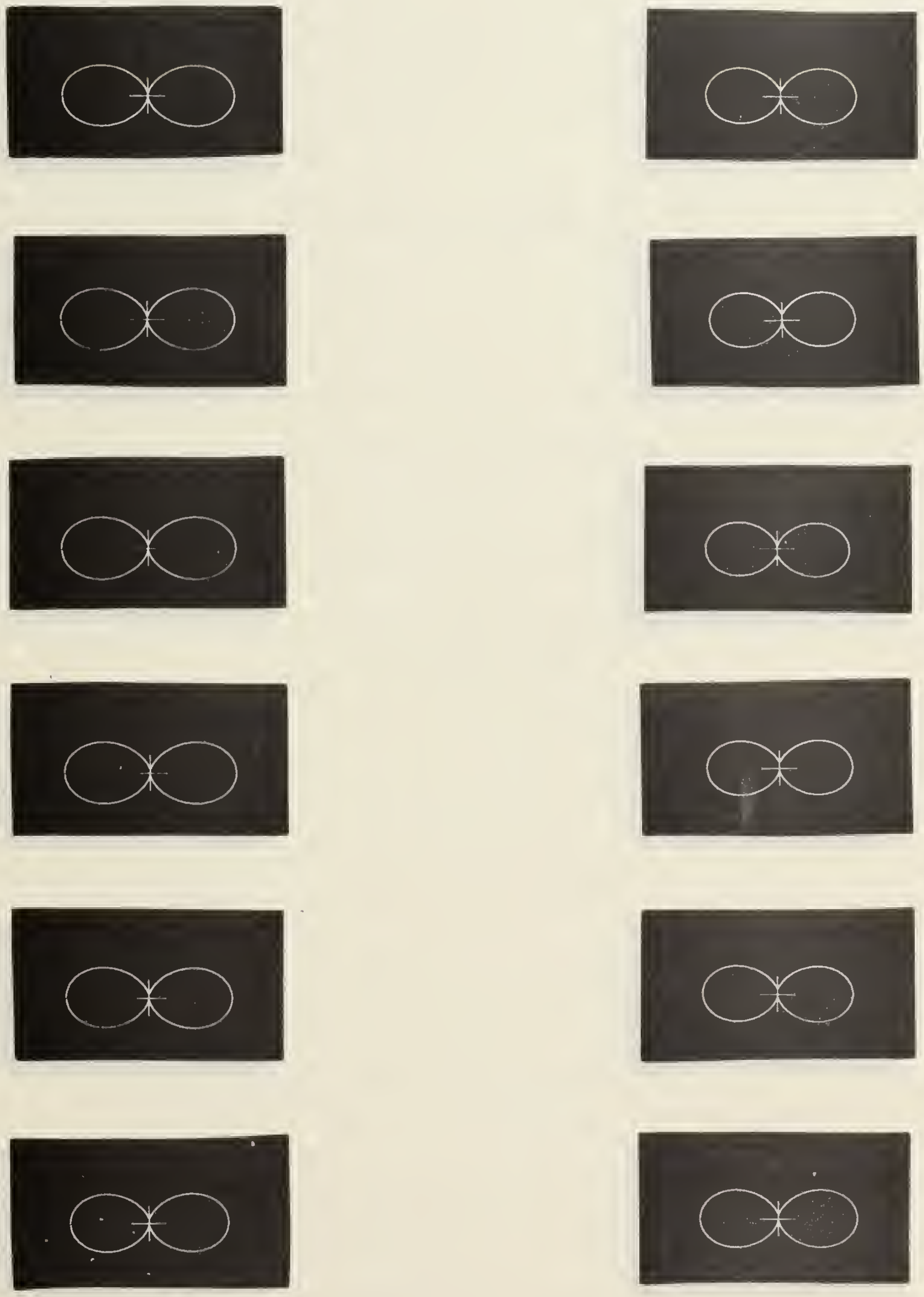


Figure B-22

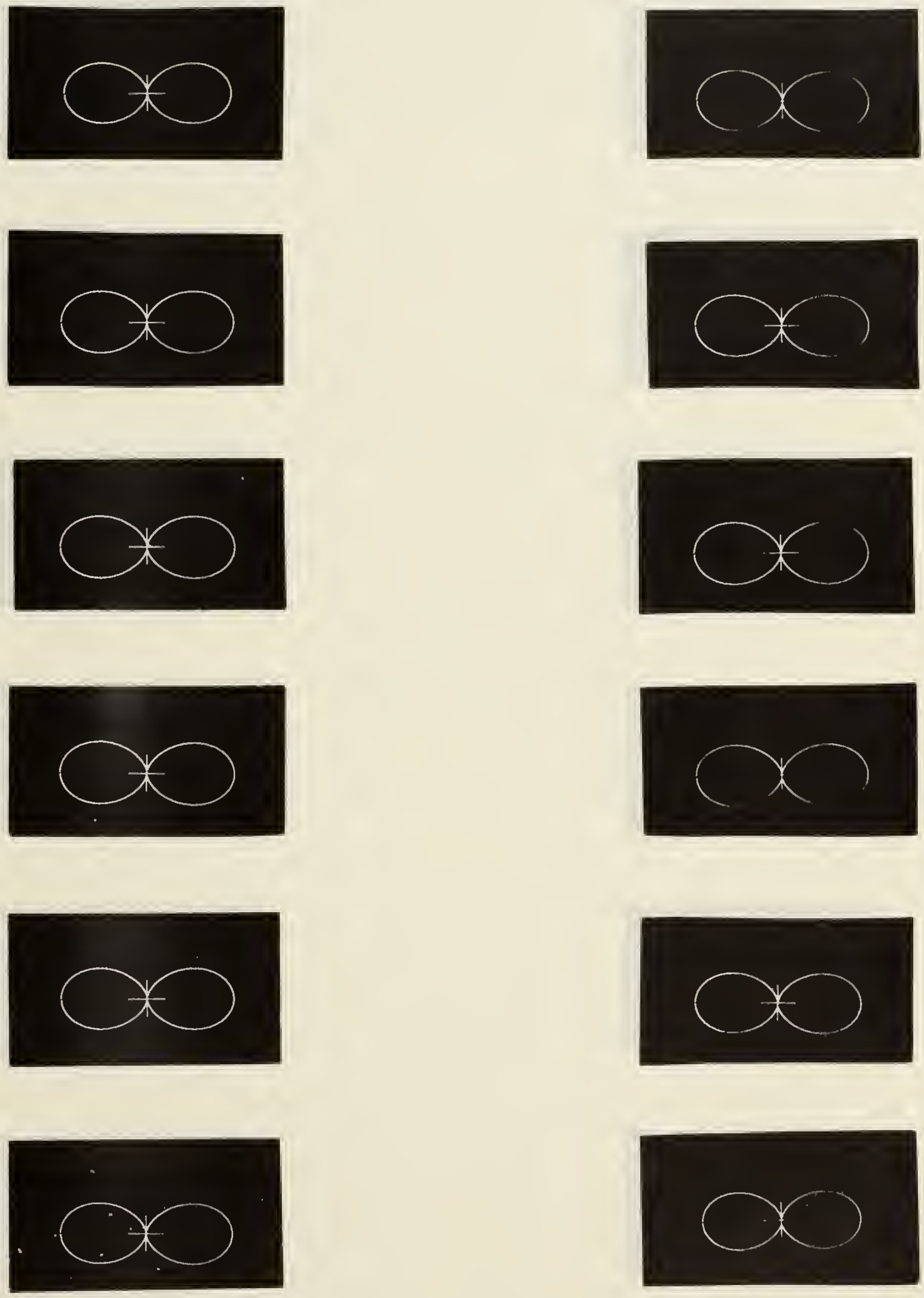


Figure B-22

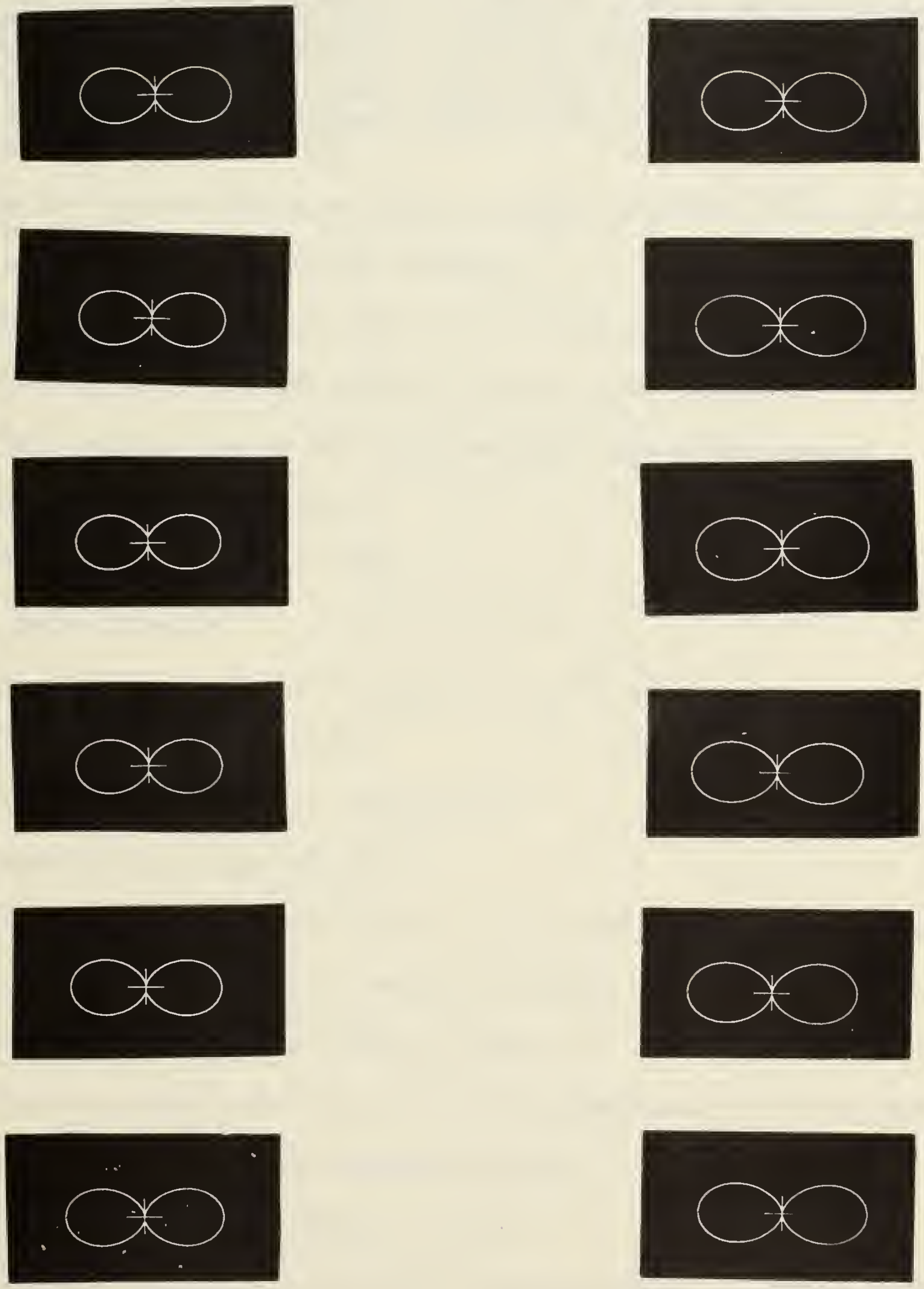


Figure B-22

APPENDIX C

ANTENNA GEOMETRY AND GAIN AND INPUT RESISTANCE EQUATIONS

This appendix details the antenna geometry of the programmed antennas and the equations used in the gain processor and input resistance processor. The sources of equations and geometry are ESSA Technical Report ESSA-ERL-110-ITS 78 and ESSA Technical Report ESSA-ERL-104-ITS 74. The spherical coordinate system used to describe antenna patterns is the IEEE standard and is shown in figure C-1 Antenna geometry for the antennas programmed is shown in figures C-2 thru C-9.

The definitions of the terms used in antenna equations are as follows:

ℓ = length of a unit radiator in meters

h = height of antenna feed point above ground plane

Θ' = Tilt angle of the antenna axis measured from the zenith

Δ' = Tilt angle of the antenna axis measured from the horizontal

Θ = Observation zenith angle

Δ = Observation elevation angle

α = Apex half angle

α_c = Complement of apex half angle

ϕ = Observation azimuth angle

ε_r = Dielectric constant of ground plane

σ = Conductivity of ground plane

R_h = Complex ground reflection factor for a horizontally polarized wave

CH = Magnitude of horizontal reflection factor

Ψ_h = Phase of horizontal reflection factor

R_v = Complex ground reflection factor for a vertically polarized wave

CV= Magnitude of vertical reflection factor

Ψ_v = Phase of vertical reflection factor

$R_{h'}$ = Complex horizontal reflection factor evaluated for normal incidence

$R_{v'}$ = Complex vertical reflection factor evaluated for normal incidence

f = Frequency in mhz

λ = wave length in meters

a = radius of ground screen

c = radius of ground screen wire

Equations for quantities that are common to all antennas programmed are as follows:

$$\lambda = \frac{3.0 \times 10^8}{f}$$

$$k = 2\Pi/\lambda$$

$$k_2 \approx \cong k \left(\varepsilon_r - j \; \frac{1.8 \times 10^4 \sigma}{f}\right)^{1/2}$$

$$R_v = \frac{\mathrm{COS}\Theta - \frac{k}{k_2}\left[1 - \left(\frac{k}{k_2}\;\mathrm{SIN}\Theta\right)^2\right]^{1/2}}{\mathrm{COS}\Theta + \frac{k}{k_2}\left[1 - \left(\frac{k}{k_2}\;\mathrm{SIN}\Theta\right)^2\right]^{1/2}}$$

$$R_h = \frac{\mathrm{COS}\Theta - \frac{k_2}{k}\left[1 - \left(\frac{k}{k_2}\;\mathrm{SIN}\Theta\right)^2\right]^{1/2}}{\mathrm{COS}\Theta + \frac{k_2}{k}\left[1 - \left(\frac{k}{k_2}\;\mathrm{SIN}\Theta\right)^2\right]^{1/2}}$$

$$R_v' = \frac{k_2 - k}{k_2 + k} \qquad R_h' = \frac{k - k_2}{k + k_2}$$

$$S1 = \mathrm{COS}\ (\psi_h - 2Kh\ \mathrm{SIN}\Delta\ )$$

$$S2 = \mathrm{SIN}\ (\Psi_h - 2Kh\ \mathrm{SIN}\Delta\ )$$

$$S3 = \mathrm{COS}\ (\Psi_v - 2Kh\ \mathrm{SIN}\Delta\ )$$

$$S4 = \mathrm{SIN}\ (\Psi_v - 2Kh\ \mathrm{SIN}\Delta\ )$$

C. 1 ARBITRARILY TILTED DIPOLE

The equations presented are for a thin, single element, center fed dipole arbitrarily oriented above a flat ground plane.

$$GI = \frac{\cos(1/2k\ell\,(\sin\Delta \sin\Delta' + \cos\Delta \cos\Delta' \sin\phi) - \cos(1/2k\ell)}{1.0 - (\sin\Delta \sin\Delta' + \cos\Delta \cos\Delta' \sin\phi)^2}$$

$$DI = \frac{\cos(1/2k\ell\,(\cos\Delta \cos\Delta' \sin\phi - \sin\Delta \sin\Delta')- \cos(1/2k\ell)}{1.0 - (\cos\Delta \cos\Delta' \sin\phi - \sin\Delta \sin\Delta')^2}$$

$$\begin{aligned} E_{\phi_1} &= (\cos\Delta' \sin\phi \sin\Delta - \sin\Delta' \cos\Delta)\cdot GI \\ &\quad - (\cos\Delta' \sin\phi \sin\Delta + \sin\Delta' \cos\Delta)\cdot DI\cdot CV\cdot S3 \end{aligned}$$

$$E_{\phi_1} = \cos\Delta' \cos\phi\,(GI + DI\cdot CH\cdot S1)$$

$$E_{\Theta_2} = (\cos\Delta' \sin\phi \sin\Delta + \sin\Delta' \cos\Delta)\cdot DI\cdot CV\cdot S4$$

$$E_{\phi_2} = \cos\Delta' \cos\phi\cdot DI\cdot CH\cdot S2$$

$$\text{Gain} = 120\cdot (E_{\Theta_1}{}^2 + E_{\Theta_2}{}^2 + E_{\phi_1}{}^2 + E_{\phi_2}{}^2)\,/Rin$$

$$S = 2h$$

$$S_x = S \sin\Theta' \cos\phi'$$

$$S_y = S \sin\Theta' \sin\phi'$$

$$S_z = S \cos\Theta$$

$$\rho = \left[S_x{}^2 + (Y_o + S_y)^2 \right]^{1/2}$$

$$\left.\begin{aligned} Y_o &= 2 \cos\Delta' \frac{h}{\lambda} \\ Z_o &= 2 \sin\Delta' \frac{h}{\lambda} \end{aligned}\right\} \text{for mutual impedance}$$

$$\left.\begin{aligned} Y_o &= \sqrt{2} \times 10^{-3} \cdot \ell/\lambda \\ Z_o &= 0 \end{aligned}\right\} \text{for self impedance}$$

$$r = \left[\rho^2 + (Z_o + S_z)^2\right]^{1/2}$$

$$r_1 = \left[\rho^2 + (Z_o + S_z + 1/2\ell)^2\right]^{1/2}$$

$$r_2 = \left[\rho^2 + (Z_o + S_z - 1/2\ell)^2\right]^{1/2}$$

$$SR = 1/r\ SIN\ (2\Pi r)$$

$$SR1 = 1/r_1\ SIN\ (2\Pi r_1)$$

$$SR2 = 1/r_2\ SIN\ (2\Pi r_2)$$

$$FACR = 2 \cdot SR\ COS\ (\Pi \ell)$$

$$CR = 1/r\ COS\ (2\Pi r)$$

$$CR1 = 1/r_1\ COS\ (2\Pi r_1)$$

$$CR2 = 1/r_2\ COS\ (2\Pi r_2)$$

$$FACX = 2 \cdot CR \cdot COS\ (\Pi \ell)$$

$$Z_{ij} = (R_{ij} + j\ X_{ij})$$

$$R_{ij} = -30 \int_{-\ell/2}^{\ell/2} \left\{ \left[\frac{1}{\rho 2} \left(SR1 \cdot (S_z + Z_o + \frac{\ell}{2}) + SR_2\ (S_z + Z_o - \frac{\ell}{2}) - FACR \cdot (S_z + Z_o) \right) \cdot (S_x 2 + Y_o S_y + S_y 2) \right] + S_z\ (FACR - SR1 - SR2) \right\} \cdot \left[\frac{SIN 2\Pi (\frac{\ell}{2} - |S|)}{S} \right] dS$$

$$X_{ij} = -30 \int_{-\ell/2}^{\ell/2} \left\{ \left[\frac{1}{\rho^2} \left(CR1 \cdot (S_z + Z_o + \frac{\ell}{2}) + CR2 \cdot (S_z + Z_o - \frac{\ell}{2}) - FACR\ (S_z + Z_o) \right) \cdot (S_x 2 + Y_o S_y + S_y 2) \right] + S_z \cdot (FACX - CR1 - CR2) \right\} \left[\frac{SIN 2\Pi\ (\frac{\ell}{2} - |S|)}{S} \right] dS$$

$Z_{11} \equiv$ self impedance

$Z_{21} \equiv$ mutual impedance

$$R_{in} = R_{11} + Real \left[Z_{21}\ (R_h'\ COS\Delta' + j\ R_v'\ SIN\Delta')\ (COS\Delta' - j\ SIN\Delta') \right]$$

C.2 VERTICAL MONOPOLE

Vertical whip antenna equations are for a base loaded vertical whip above a flat ground plane.

$$S3 = \cos(\Psi_v)$$

$$S4 = \sin(\Psi_v)$$

$$A = \cos(k\ell \sin\Delta) - \cos(k\ell)$$

$$B = \sin(k\ell \sin\Delta) - \sin\Delta \sin(k\ell)$$

$$\text{Gain} = \left\{ \frac{\left[A\cdot(1+CV\cdot S3) + B\cdot CV\cdot S4\right]^2 + \left[A\cdot CV\ S4 + B\cdot(1-CV\cdot S3)\right]^2}{R_{in}\ \cos^2\Delta} \right.$$

$$R_{in} = 15 \left\{ \left[2 + 2\cos(2k\ell)\right]\cdot\left[\ell n(2k\ell) + \gamma - Ci(2k\ell)\right] - \right.$$

$$\cos(2k\ell)\cdot\left[\ell n(4k\ell) + \gamma - Ci(4k\ell)\right] -$$

$$\left. 2\sin(2k\ell)\cdot\left[\frac{\pi}{2} + Si(2k\ell)\right] + \sin(2k\ell)\cdot\left[\frac{\pi}{2} + Si(4k\ell)\right] \right\}$$

$$\gamma = .577$$

$$Ci(x) = -\int_x^{\infty} \frac{\cos t}{t}\, dt$$

$$Si(x) = -\int_x^{\infty} \frac{\sin t}{t}\, dt$$

C.3 VERTICAL WHIP WITH GROUND SCREEN

The vertical whip with ground screen is a single monopole above a flat ground with a radial conductor ground system consisting of N equally spaced radial conductors. A value of 120 is used for N and 1 cw wire is assumed.

$$S3 = COS\ \psi_v$$

$$S4 = SIN\ \psi_v$$

$$A = COS\ (k\ell SIN\Delta) - COS\ (k\ell) \qquad B = SIN\ (k\ell SIN\Delta) - SIN\Delta SIN\ (k\ell)$$

$$Gain = \frac{[A\cdot(1 + CV\cdot S3) + B\cdot CV\cdot S4]^2 + [A\cdot CV\cdot S4 + B\cdot(1-CV\cdot S3)]^2\ [A_3^2 + B_3^2]}{R_{in}}$$

$$A_3+jB_3 = \frac{1 - \eta SIN\theta \int_o^{ka} \left[e^{-j(x^2+k^2\ell^2)^{1/2}} - e^{-jx}COS(k\ell) \right] J_1(xSIN\theta)dx}{120\Pi\ SIN(k\ell)\ [COS(k\ell COS\theta) - COS(k\ell)]}$$

$$\eta = \left[\frac{j\mu\omega}{\sigma + j\omega\varepsilon}\right]^{1/2}$$

$R_1 = R_{in}$ of vertical whip (C.2)

$$\Delta Z_1 = \frac{\eta}{4\Pi SIN^2(k\ell)} \Big\{ e^{j2k\ell}Ei\left[-j2k(r_o + \ell)\right] + e^{-j2k\ell}Ei\left[-j2k(r_o-\ell)\right]$$

$$+ 2COS^2(k\ell)\ Ei[-j2ka] + 4\ COS(k\ell)\ Ei\left[-jkr_1\right]$$

$$- 4COS(k\ell)e^{-jk\ell}Ei\left[-jk(r_1 - \ell)\right] - 4\ COS(k\ell)e^{jk\ell}Ei\left[-jk(r_1+\ell)\right]\Big\}$$

$$\Delta Z_2 = -\int_o^a \left[\frac{\eta_e\eta}{\eta + \eta_e}\right] \left[\frac{\left(e^{-jk(\rho^2+\ell^2)^{1/2}} - e^{-jk\rho}\ COS(k\ell)\right)^2}{2\Pi\rho\ SIN^2(k\ell)}\right] d\rho$$

$$Ei\ (\pm\ jx) = Ci(x) \pm j\ Si(x)$$

$$r_o = (a^2+\ell^2)^{1/2}$$

$$r_1 = a + (a^2+\ell^2)^{1/2}$$

$$\eta = \left[\frac{j\omega\mu}{\sigma+j\omega\varepsilon}\right]^{1/2}$$

$$\eta_e \left(\frac{j\ 240\Pi^2\rho}{N\lambda}\right) \ell n\left(\frac{\rho}{Nc}\right)$$

$$R_{in} = R_1 + Real\ (\Delta Z_1 + \Delta Z_2)$$

C. 4 INVERTED L

The inverted L antenna equations are for a long wire antenna that is base loaded and arranged in an inverted L configuration.

$$A = \mathrm{COS}(k\ell)\ \mathrm{COS}\ (kh\mathrm{SIN}\Delta) - \mathrm{SIN}\Delta\ \mathrm{SIN}\ (k\ell)\ \mathrm{SIN}\ (kh\mathrm{SIN}\Delta) - \mathrm{COS}\ (k\ (h+\ell))$$

$$B = \mathrm{SIN}\Delta\ \mathrm{SIN}\ (k\ell)\ \mathrm{COS}\ (kh\ \mathrm{SIN}\Delta) + \mathrm{COS}\ (k\ell)\ \mathrm{SIN}\ (kh\ \mathrm{SIN}\Delta) - \mathrm{SIN}\Delta\ \mathrm{SIN}\ (k\ (h+\ell)\ )$$

$$GI = \mathrm{SIN}\ (k\ell\ \mathrm{COS}\Delta\ \mathrm{SIN}\ \phi) - \mathrm{COS}\Delta\ \mathrm{COS}\ \phi\ \mathrm{SIN}\ (k\ell)$$

$$GR = \mathrm{COS}\ (k\ell\ \mathrm{COS}\Delta\ \mathrm{SIN}\ \phi) - \mathrm{COS}\ (k\ell)$$

$$|E_\Theta|^2 = \left[\frac{\mathrm{SIN}\ \phi\ \mathrm{SIN}\Delta\ \left[GR(1.0 - CV\cdot S3) + GI\cdot CV\cdot S4)\right]}{1.0 - \mathrm{COS}^2\Delta\ \mathrm{SIN}^2\ \phi} - \frac{A\ (1.0 + CV\cdot\ \mathrm{COS}\ \psi_v + B\ CV\cdot \mathrm{SIN}\psi_v}{\mathrm{COS}\Delta} \right]^2$$

$$+ \left[\frac{\mathrm{SIN}\phi\ \mathrm{SIN}\Delta\ (GI\ (1.0 - CV\cdot S3) - GR\cdot CV\cdot S4}{1.0 - \mathrm{COS}^2\Delta\ \mathrm{SIN}^2\ \phi} - \frac{B\ (1.0 - CV\cdot \mathrm{COS}\ \psi_v) + A\cdot CV\cdot \mathrm{SIN}\ \psi_v}{\mathrm{COS}\Delta} \right]^2$$

$$|E_\phi|^2 = \left[\frac{\mathrm{COS}\ \phi}{1 - \mathrm{COS}^2\Delta\ \mathrm{COS}^2\ \phi} \right] \cdot \left\{ [GR(1.0 + CH\cdot S1) - GI\cdot CH\cdot S2]^2 + [GI\ (\ 1.0 + CH\cdot S1) + GR\cdot CH\cdot S2\ ]^2 \right\}$$

$$\mathrm{Gain} = 30\cdot 0\ \frac{\left[|E_\phi|^2 + |E_\phi|^2 \right]}{\mathrm{Rin}}$$

$$\mathrm{Si}(x) = \int_x^\infty \frac{\mathrm{SIN}\ x}{x}\ dx$$

$$\mathrm{Rin} = 60 \left[1.41 + \ell n \left(\frac{2\ell}{\lambda} \right) + \frac{\mathrm{SIN}\ (2k\ell)}{2k\ell} \right]$$

$$+ 30.0 \left\{ - 1/2\ \mathrm{COS}\ (2kh) \left[(\ell n\ (2kh) + 1.270 - \mathrm{Ci}\ (4kh) \right] \right.$$

$$+ (1.0 + \mathrm{COS}\ (2kh)) \left[\ell n\ (2kh) + 0.577 - \mathrm{Ci}\ (2kh)) \right]$$

$$\left. - \mathrm{SIN}\ (2kh) \left[1/2\ \mathrm{Si}\ (4kh) - \mathrm{Si}\ (4k\ell) \right] \right\}$$

C.5 SLOPING LONG WIRE

The equations for this antenna are for a base loaded longwire antenna arranged in a sloping configuration; the antenna zenith angle may be assigned values of 0 thru 90 degrees.

$$\text{CIG} = \frac{\text{COS}\,[k\ell\,(\text{SIN}\Delta\ \text{SIN}\Delta' + \text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi)] - \text{COS}\,(k\ell)}{1.0 - (\text{SIN}\Delta\ \text{SIN}\Delta' + \text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi)^2}$$

$$\text{SIG} = \frac{\text{SIN}\,[k\ell\,(\text{SIN}\Delta\ \text{SIN}\Delta' + \text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi)] - (\text{SIN}\Delta\text{SIN}\Delta' + \text{COS}\Delta\text{COS}\Delta'\text{COS}\phi)\ \text{SIN}(k\ell)}{1.0 - (\text{SIN}\Delta\ \text{SIN}\Delta' + \text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi)^2}$$

$$\text{CIGP} = \frac{\text{COS}\,[k\ell)\,(\text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi - \text{SIN}\Delta\ \text{SIN}\Delta')] - \text{COS}\,(k\ell)}{1.0 - (\text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi - \text{SIN}\Delta\ \text{SIN}\Delta')^2}$$

$$\text{SIGP} = \left[\frac{\text{SIN}\,[k\ell)\,(\text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi - \text{SIN}\Delta\ \text{SIN}\Delta')]}{1.0 - (\text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi - \text{SIN}\Delta\ \text{SIN}\Delta')^2} + \frac{(\text{SIN}\Delta\ \text{SIN}\Delta' - \text{COS}\Delta\ \text{COS}\Delta'\ \text{COS}\,\phi)\ \text{SIN}\,(k\ell)}{}\right]$$

$$E_{\phi_1} = -\,\text{COS}\Delta'\ \text{SIN}\,\phi\left[\text{CIG} + \text{CH}\cdot(\text{CIGP}\ \text{COS}\,\psi_h - \text{SIGP}\cdot\text{SIN}\,\psi_h)\right]$$

$$E_{\phi_2} = -\,\text{COS}\Delta'\ \text{SIN}\,\phi\left[\text{SIG} + \text{CH}\ (\text{CIGP}\cdot\text{SIN}\,\psi_h\ \ \text{SIGP}\ \text{COS}\,\psi_h)\right]$$

$$E_{\Theta_1} = \text{CIG}\ (\text{COS}\Delta'\ \text{COS}\,\phi\ \text{SIN}\Delta - \text{SIN}\Delta'\ \text{SIN}\Delta) + \text{CV}\ (\text{COS}\Delta'\ \text{COS}\,\phi\ \text{SIN}\Delta + \text{SIN}\Delta'\ \text{COS}\Delta)\cdot\left[\text{CIGP}\cdot\text{COS}\,\psi_v - \text{SIGP}\cdot\text{SIN}\,\psi_v\right]$$

$$E_{\Theta_2} = \text{SIG}\ (\text{COS}\Delta'\ \text{COS}\,\phi\ \text{SIN}\Delta - \text{SIN}\Delta'\ \text{COS}\Delta) - \text{CV}\ (\text{COS}\Delta'\ \text{COS}\,\phi\ \text{SIN}\Delta + \text{SIN}\Delta'\ \text{COS}\Delta)\left[\text{CIGP}\cdot\text{SIN}\,\psi_v + \text{SIGP}\cdot\text{COS}\,\psi_v\right]$$

$$\text{Gain} = 30\left[E_{\phi_1}^{\,2} + E_{\phi_2}^{\,2} + E_{\phi_1}^{\,2} + E_{\phi_2}^{\,2}\right]/\ \text{Rin}$$

$$\text{Rin} = 30\left\{1/2\left[\ell n\,(k\ell) + .577 + \text{Ci}\,(4k\ell)\right] + 0.693 + \text{COS}\,(k\ell)\left[\text{COS}\,k\ell\,(\ell n\,(k\ell) + .577 - 2.0\,\text{Ci}\,(2k\ell) + \text{Ci}\,(4k\ell)) - \text{SIN}\,(k\ell)\,(\text{Si}\,(4k\ell) - 2.0\,\text{Si}\,(2k\ell)\right]\right\}$$

$$\text{Ci}(x) = -\int_x^{\infty}\frac{\text{COS}t}{t}\,dt$$

$$\text{Si}(x) = -\int_x^{\infty}\frac{\text{SIN}t}{t}\,dt$$

C. 6 TERMINATED SLOPING VEE

The terminated sloping vee equations are for two sloping longwire antennas arranged in a vee configuration. The feed point is the apex of the vee. The elements are fed 180 degrees out of phase. The elements of the vee are terminated in 370 ohm non inductive resistors.

$$\cos\psi_1 = \sin\Delta \sin\Delta' + \cos\Delta \cos\Delta' \cos(\phi - \alpha)$$

$$\cos\psi_2 = \sin\Delta \sin\Delta' + \cos\Delta \cos\Delta' \cos(\phi + \alpha)$$

$$\cos\psi_3 = -\sin\Delta \sin\Delta' + \cos\Delta \cos\Delta' \cos(\phi - \alpha)$$

$$\cos\psi_4 = -\sin\Delta \sin\Delta' + \cos\Delta \cos\Delta' \cos(\phi + \alpha)$$

$$\cos\psi_5 = \cos\Delta \sin\Delta' + \sin\Delta \cos\Delta' \cos(\phi - \alpha)$$

$$\cos\psi_6 = \cos\Delta \sin\Delta' + \sin\Delta \cos\Delta' \cos(\phi + \alpha)$$

$$\cos\psi_7 = -\cos\Delta \sin\Delta' + \sin\Delta \cos\Delta' \cos(\phi - \alpha)$$

$$\cos\psi_8 = -\cos\Delta \sin\Delta' + \sin\Delta \cos\Delta' \cos(\phi + \alpha)$$

$$U_i = k\ell\,(1.0 - \cos\psi_i) \qquad i = 1, 2, 3, 4$$

$$A = \frac{\cos\psi_7\,(\cos(U_1) - 1.0)}{U_1} - \frac{\cos\psi_8\,(\cos(U_2) - 1)}{U_2}$$

$$+ CV \cdot \left\{ \frac{\cos\psi_6 \left[S3(\cos(U_4) - 1.0)\ S4 + \sin(U_4)\right]}{U_4} \right.$$

$$\left. - \cos\psi_5 \frac{[\cos(U_3) - 1.0)\ S3 + \sin(U_3)\ S4]}{3} \right\}$$

$$B = \frac{\cos\psi_8 \sin(U_2)}{U_2} - \frac{\cos\psi_7 \sin(U_1)}{U_1}$$

$$+ CV \left\{ \frac{\cos\psi_5 \left(\sin(U_3)\ S3 - (\cos(U_3) - 1.0)\ S4\right)}{} \right.$$

$$+ \cos\psi_6 \left(\frac{(\cos(U_4) - 1.0)\ S4 - \sin(U_4)\ S3}{U_3} \right)$$

$$\left. + \cos\psi_6 \left(\frac{(\cos(U_4) - 1.0)\ S4 - \sin(U_4)\ S3}{U_4} \right) \right\}$$

$$C = \frac{\sin(\phi+\alpha)\,(\cos(U_2) - 1.0)}{U_2} - \frac{\sin(\phi-\alpha)\,(\cos(U_1) - 1.0)}{U_1}$$

$$+ CH \left\{ S1 \left[\frac{\sin(\phi+\alpha)\,(\cos(U_4) - 1.0)}{U_4} - \frac{\sin(\phi-\alpha)\,(\cos(U_3) - 1.0)}{U_3} \right] \right.$$

$$\left. -S2 \left[\frac{\sin(\phi-\alpha)\,\sin(U_3)}{U_3} - \frac{\sin(\phi+\alpha)\,\sin(U_4)}{U_4} \right] \right\}$$

$$D = \frac{\sin(\phi-\alpha)\sin(U_3)}{U_3} - \frac{\sin(\phi+\alpha)\,\sin(U_4)}{U_4}$$

$$+ CH \left\{ \left[\frac{\sin(\phi-\alpha)\,\sin(U_3)}{U_3} - \frac{\sin(\phi+\alpha)\,\sin(U_4)}{U_4} \right] \cdot S1 \right.$$

$$\left. + \left[\frac{\sin(\phi+\alpha)\,(\cos(U_4) - 1.0)}{U_4} - \frac{\sin(\phi-\alpha)\,(\cos(U_3) - 1.0)}{U_3} \right] S2 \right\}$$

$$\text{Gain} = 0.05 \left[A^2 + B^2 + \cos^2\Delta' \quad (C^2 + D^2) \right]$$

C. 7 HORIZONTAL RHOMBIC

The horizontal rhombic antenna equations were developed under the assumption of uniform current distribution of the effective value of current. The antenna is loaded at the apex and terminated in dissipation lines at the opposite corner.

$$U_1 = 1.0 - \text{COS}\Delta\ (\text{SIN}\ \alpha_c\ \ \text{COS}\ \phi + \text{COS}\ \alpha_c\ \ \text{SIN}\ \phi)$$

$$U_2 = 1.0 - \text{COS}\Delta\ (\text{SIN}\ \alpha_c\ \ \text{COS}\ \phi - \text{COS}\ \alpha_c\ \ \text{SIN}\ \phi)$$

$$\text{Gain} = 2.16 \left[\frac{\text{COS}\ \alpha_c\ \ \text{SIN}\ (1/2\ k\ell U_1)\text{SIN}\ (1/2\ k\ell U_2)}{U_1U_2}\right]^2 \cdot$$

$$\left[\left(\text{COS}\ \phi - \text{SIN}\ \alpha\ \ \text{COS}\ \ \right)^2 (\text{CH}^2 + 1.0 + 2.0 \cdot \text{CH} \cdot \text{S1}) + \text{SIN}^2\Delta\ \ \text{SIN}^2\ \phi\ \ (\text{CV}^2 + 1.0 - 2.0 \cdot \text{CV} \cdot \text{S3})\right)\right]$$

C. 8 VERTICAL HALF RHOMBIC

The vertical half rhombic are for a base loaded longwire arranged in the vertical half rhombic configuration and terminated in a 400-500 ohm non-inductive resistor.

$$S1 = SIN\ (K\ (1.0 - COS\ \psi_1))$$

$$C1 = COS\ (K\ (1.0 - COS\ \psi_1))$$

$$S2 = SIN\ (K\ (1.0 - COS\ \psi_2))$$

$$C2 = COS\ (K\ (1.0 - COS\ \psi_2))$$

$$COS\ \psi_1 = COS\Delta\ COS\Delta'\ COS\ \phi - SIN\Delta\ SIN\Delta'$$

$$COS\ \psi_2 = COS\Delta\ COS\Delta'\ COS\ \phi + SIN\Delta\ SIN\Delta'$$

$$R1 = \frac{1 - C1}{1.0 - COS\ \psi_1} \qquad I1 = \frac{S1}{1.0 - COS\ \psi_1}$$

$$R2 = \frac{C1\ (1.0 - C2) + S1 \cdot S2}{1.0 - COS\ \psi_2} \qquad I2 = \frac{C1 \cdot S2 - S1\ (1.0 - C2)}{1.0 - COS\ \psi_2}$$

$$R3 = (1.0 - C1)\ COS\ (2k\ell\ SIN\Delta'\ SIN\Delta) + S1\ SIN\ (2k\ell\ SIN\Delta'\ SIN\Delta)$$

$$I3 = S1\ COS\ (2k\ell\ SIN\Delta'\ SIN\Delta\ ) - (1.0 - C1)\ SIN\ (\frac{4\Pi\ell}{\lambda}\ SIN\Delta'\ SIN\Delta)$$

$$F1 = \frac{I3 \cdot C1 - R3 \cdot S1}{1.0 - COS\ \psi_1}$$

$$F2 = R3 \cdot C1 + I3 \cdot S1$$

$$F3 = \frac{1.0 - C2}{1.0 - COS\ \psi_2}$$

$$F4 = \frac{S2}{1 - COS\ \psi_2}$$

$$RB = R1 + R2 - CV\left[(F2 + F3)\ S3 - (F1 + F4)\ S4\right]$$

$$B1 = I1 + I2 - CV\left[(F2 + F3)\ S4 + (F1 + F4)\ S3\right]$$

$$RC = R2 - R1 + CV\left[(F2 - F3)\ S3 - (F1 - F4)\ S4\right]$$

$$CC = I2 - I1 + CV\left[(F2 - F3)\ S4 + (F1 - F4)\ S3\right]$$

$$RA = R1 + R2 + CH\left[(F2 + F3)\ S1 - (F1 + F4)\ S2\right]$$

$$A1 = I1 + I2 + CH\left[(F2 + F3)\ S2 + (F1 + F4)\ S1\right]$$

$$\text{Gain} = 0.1\Big[(RB\ \cos\Delta'\ \cos\phi\ \sin\Delta + RC\ \sin\Delta'\ \cos\Delta)^2$$

$$+ (B1\ \cos\Delta'\ \cos\phi\ \sin\Delta + CC\ \sin\Delta'\ \cos\Delta)^2$$

$$+ (RA\ \cos\Delta'\ \sin\phi)^2 + (AI\ \cos\Delta'\ \sin\phi)^2\Big]$$

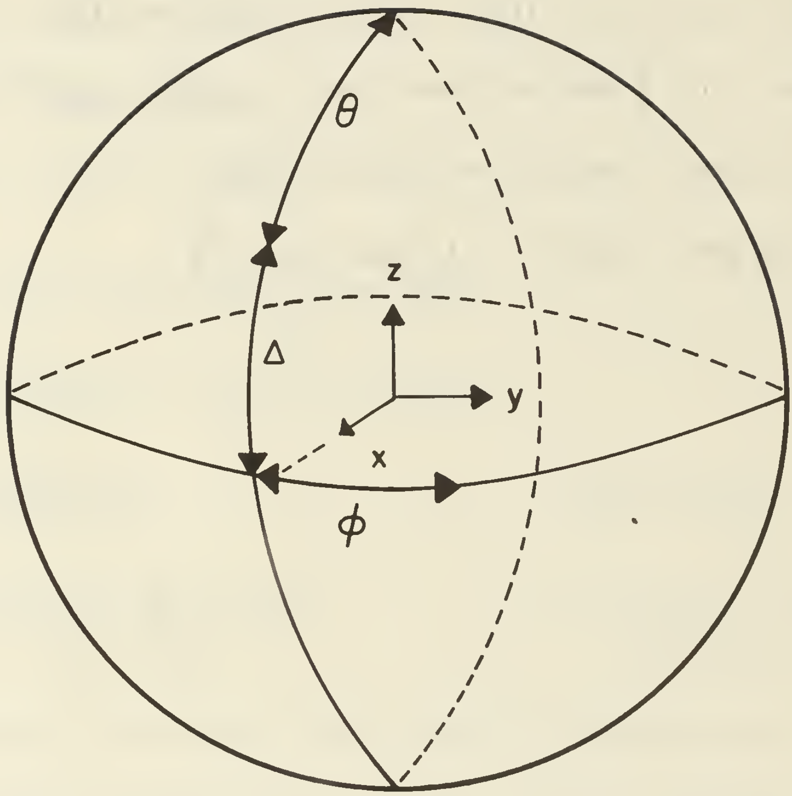
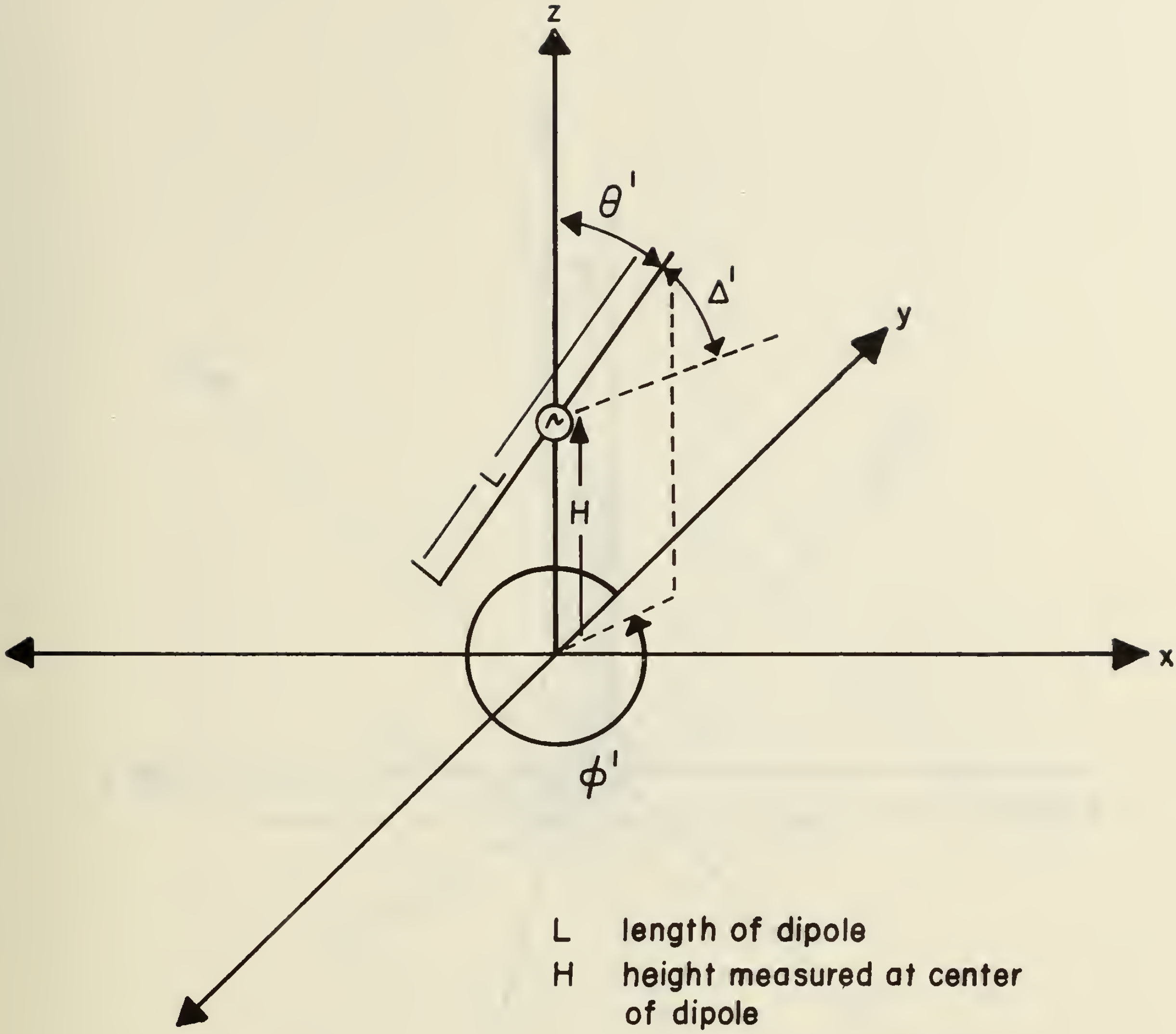


Figure C-1
Spherical Coordinate System



L length of dipole

H height measured at center of dipole

θ' Tilt angle (measured in zenith)

Δ' Tilt angle (measured in elevation above horizontal)

ϕ' Train angle (measured in azimuth)

Figure C-2

Arbitrarily Tilted Dipole Geometry

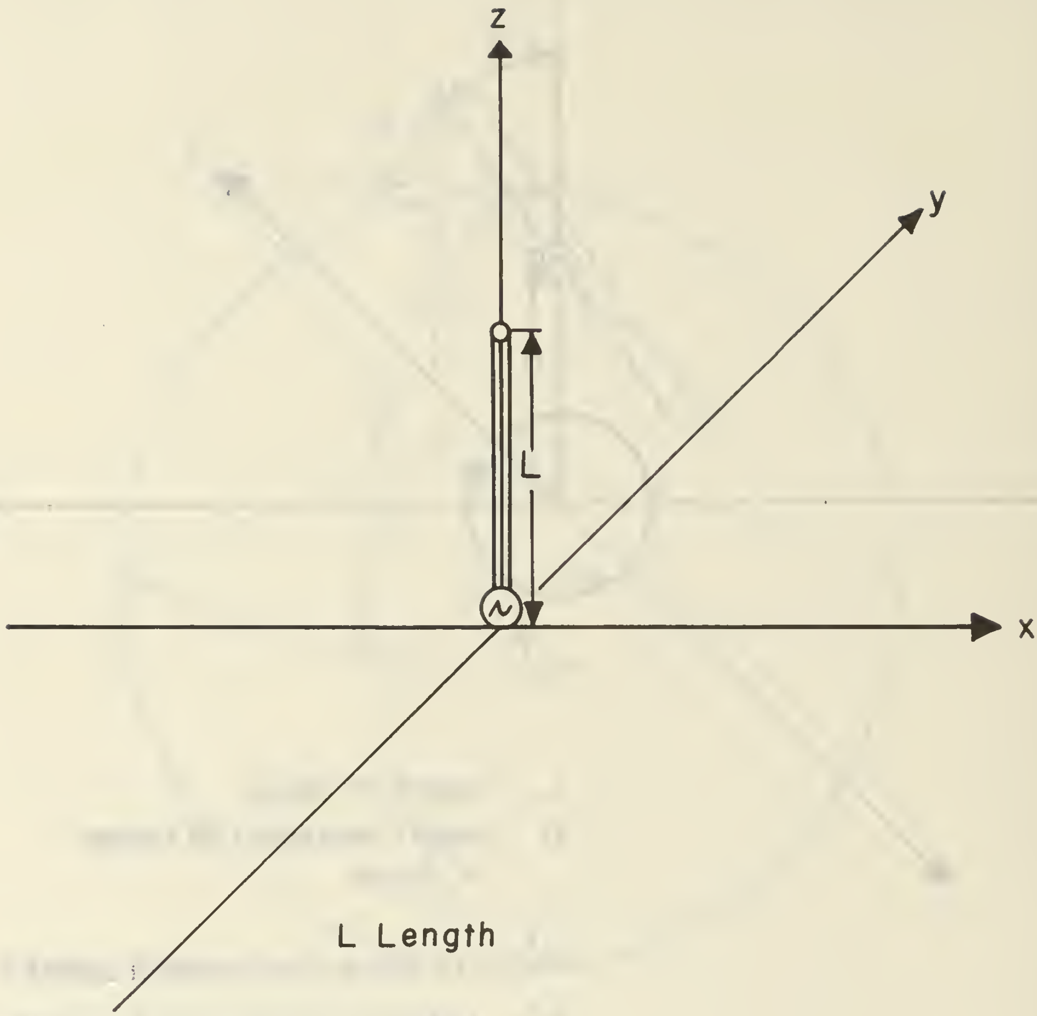
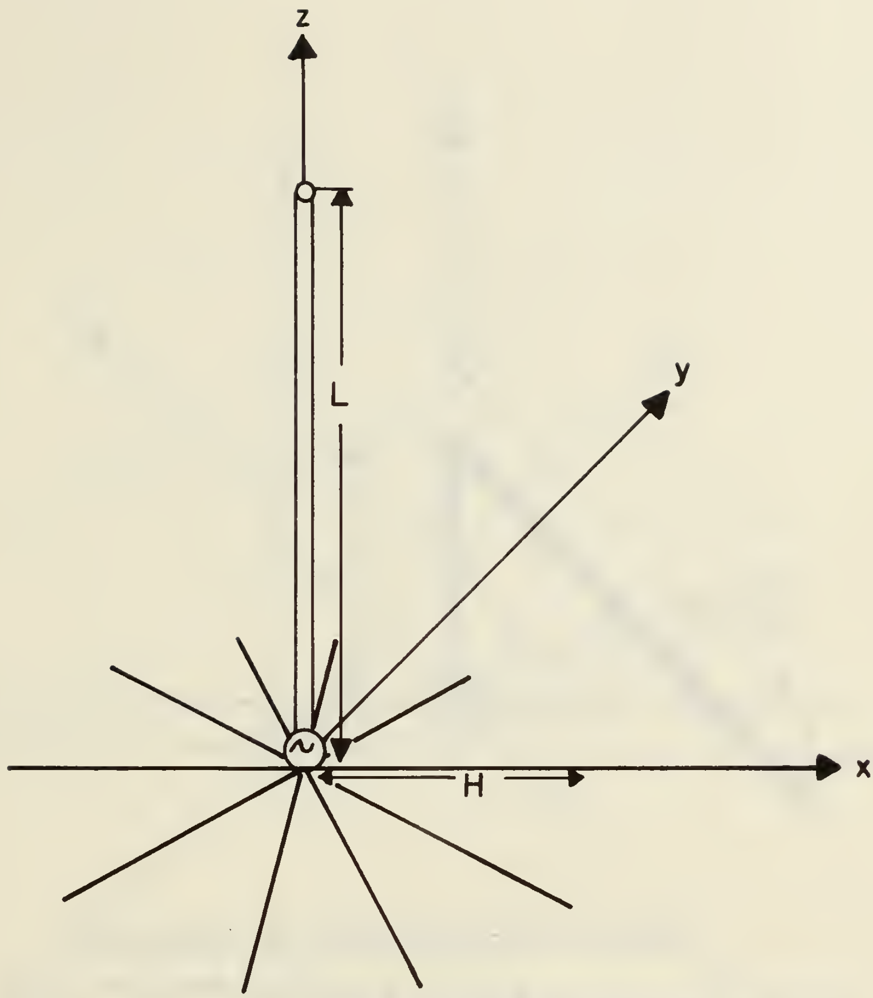


Figure C-3
Vertical Whip Geometry



L length of whip
H radius of ground screen radial elements

Figure C – 4
Vertical Whip with Ground Screen Geometry

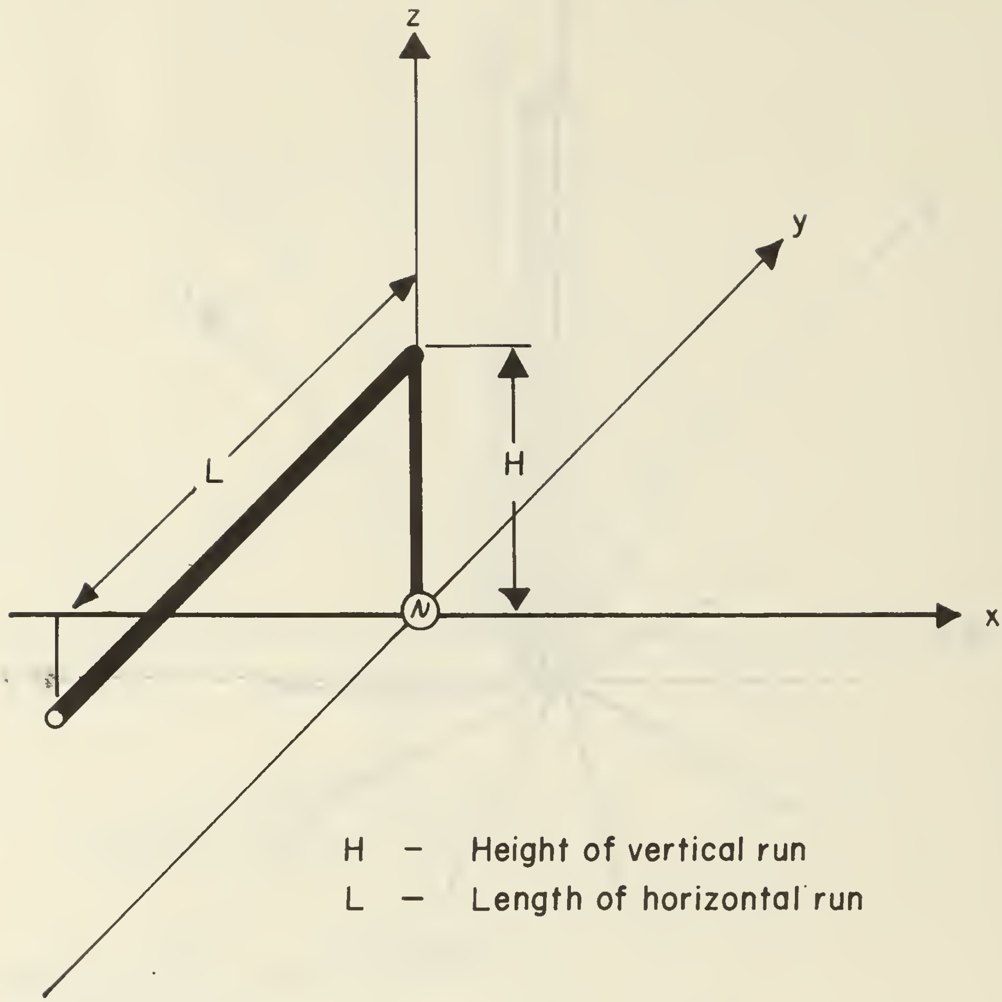


Figure C-5

Inverted L Geometry

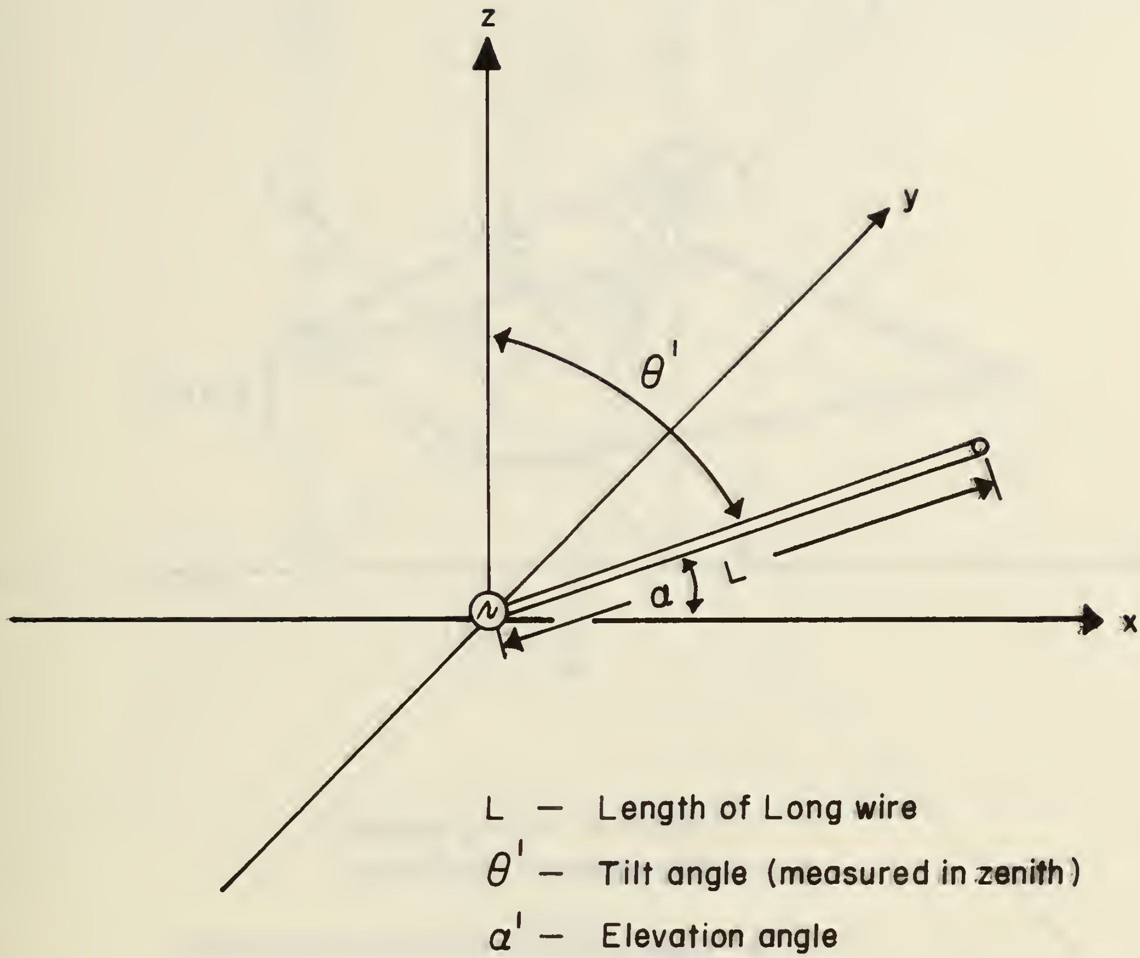
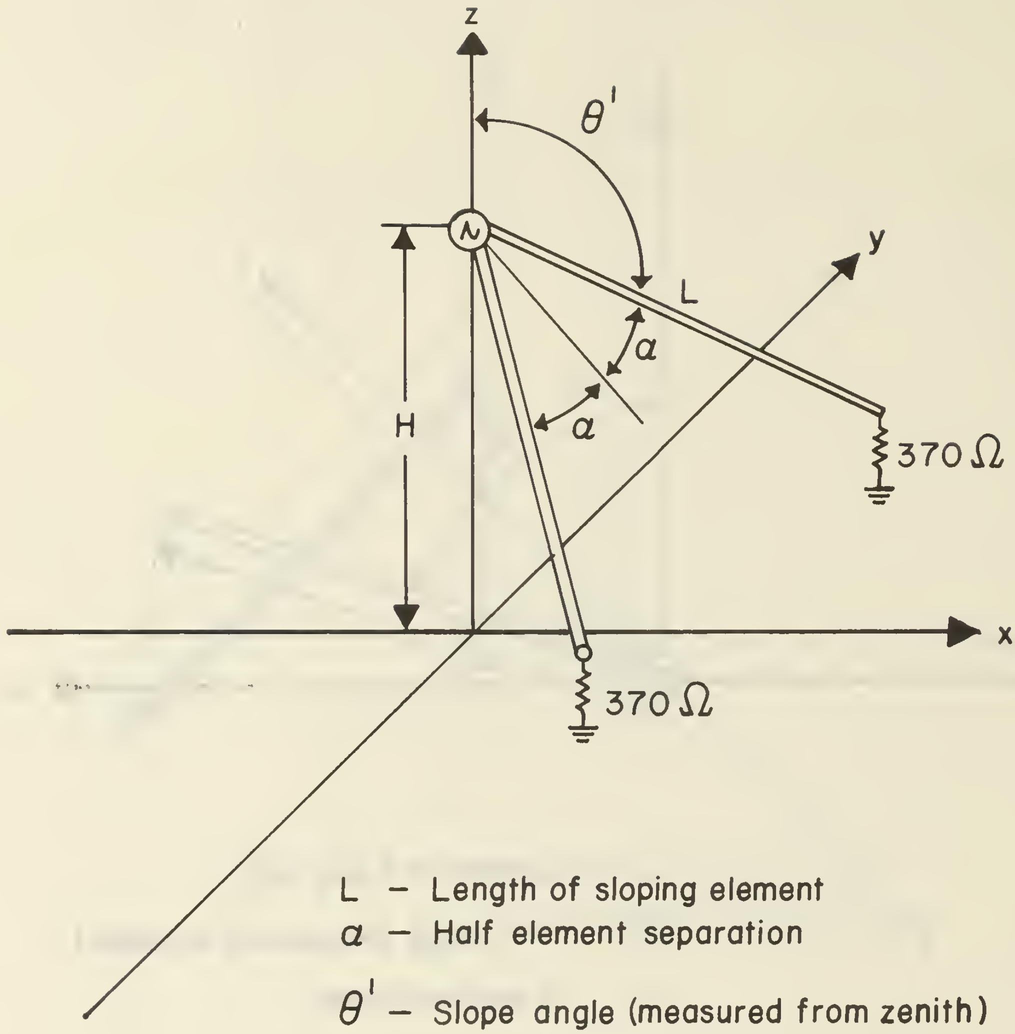
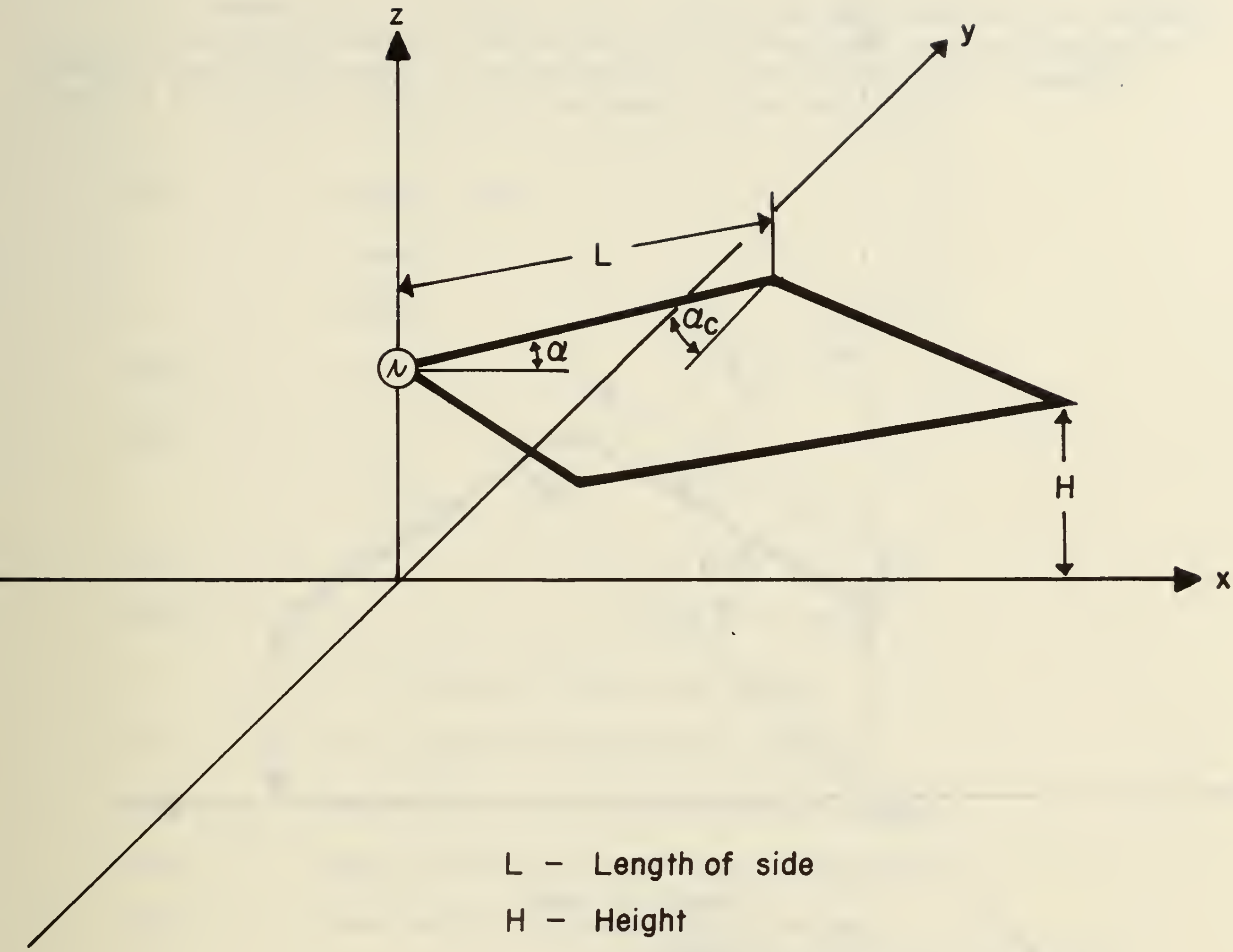


Figure C-6
Sloping Long-Wire Geometry



L – Length of sloping element
α – Half element separation
θ' – Slope angle (measured from zenith)
H – Height of load point

Figure C-7
Terminated Sloping Vee Geometry



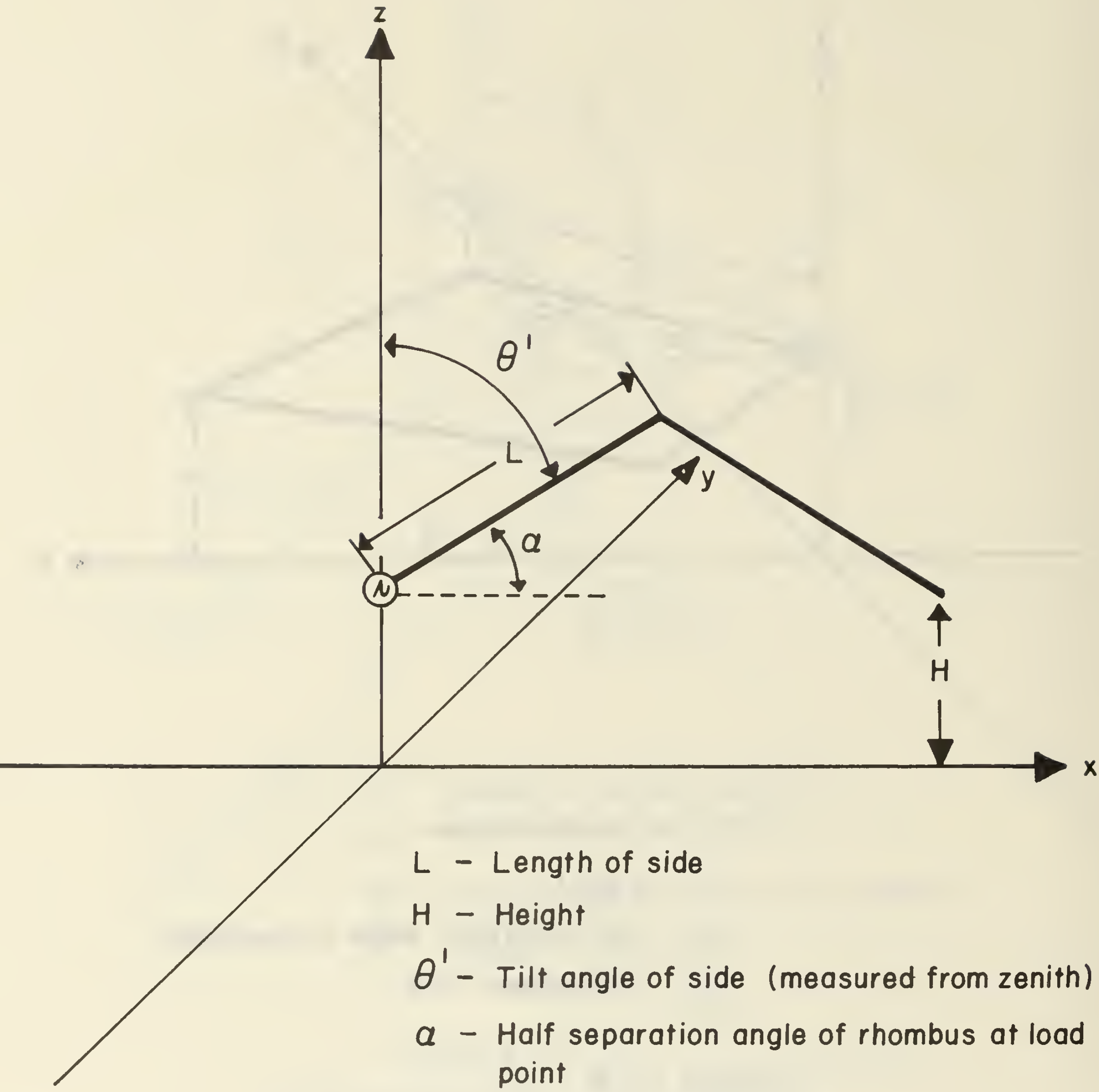
L – Length of side

H – Height

α – Half separation angle at load point

α_c – Complement of α

Figure C-8
Rhombic Geometry



L – Length of side

H – Height

θ' – Tilt angle of side (measured from zenith)

α – Half separation angle of rhombus at load point

Figure C-9

Vertical Half-Rhombic Geometry

APPENDIX D

PROGRAM LISTING

This appendix is a listing of the Fortran implementation of the antenna pattern graphics program. The listing is preceded by a partial listing of definitions of the computer variables used. Variables used in graphics display processors only were not included in the below list.

ANTN	Antenna Type
L	length
H	height
PHIPR	ϕ'
THEPR	Θ'
F	f in mhz
EPSLN	ε_r
SIGMA	α
M	Θ in degrees (observation zenith)
KAY	ϕ in degrees (observation azimuth)
PAR	Reinitialize and Log Gain option command
ISTRH	Save horizontal pattern option command
ISTRV	Save vertical pattern option command
ALPH	α
ALPCM	α_c
DLPRI	Δ'
LMDA	λ
K	k
C2	k_2
RHPRI	R_h'
RVPRI	R_v'
S	S

SX	S_x
SY	S_y
SZ	S_z
YO	Y_o
ZO	Z_o
ROW	ρ
R	r
R1	r_1
R2	r_2
PI	Π
RIN	R_{in}
THETA	Θ
PHI	ϕ
KCOS	$\cos(\Theta)$
RV	R_v
RH	R_h
SIGHV	ψ_v
SIGHH	ψ_h
DELTA	Δ
COSDL	$\cos(\Delta)$
SINDL	$\sin(\Delta)$
SINDP	$\sin(\Delta')$
COSDP	$\cos(\Delta')$
SINPI	$\sin(\phi)$
COSPI	$\cos(\phi)$

ETHT1	E_{Θ_1}
ETHT2	E_{Θ_2}
EPHI1	E_{ϕ_1}
EPHI2	E_{ϕ_2}
G	Gain (relative pattern)
GAIN	Max Gain
NORM	Max value of linear gain
EPHI	$\lvert E_{\phi} \rvert^2$
ETHET	$\lvert E_{\phi} \rvert^2$
KOS1	COS ψ_1
KOS2	COS ψ_2
KOS3	COS ψ_3
KOS4	COS ψ_4
KOS5	COS ψ_5
KOS6	COS ψ_6
KOS7	COS ψ_7
KOS8	COS ψ_8
COSU1	COS (U1)
COSU2	COS (U2)
COSU3	COS (U3)
COSU4	COS (U4)
SINU1	SIN (U1)
SINU2	SIN (U2)
SINU3	SIN (U3)

SINU4	SIN (U4)
SINAC	SIN (α_c)
COSAC	COS (α_c)
IRCAL	Recall saved pattern option command
ISEA	Sea State
ICRS	Sea direction
SIGL	Log_{10} (G (M, KAY))
ADA	η
DPHIP	$\Delta\phi$
WAVE	wave
DLTI	$\Delta\Theta_1$
DLT2	$\Delta\Theta_2$
DLT3	$\Delta\Theta_3$
SIND3	SIN ($\Delta\Theta3$)
SINA	SIN ($\Delta\phi$)
COSA	COS ($\Delta\phi$)
VAR	ωt (wave)
Z	Z
RGRAL	Rij
XGRAL	Xij
CEE	C
SRFAC	$(A_3 + jB_3)$
DLTZ1	ΔZ_1
DLTZ2	ΔZ_2
CV	$\|Rv\|$
CH	$\|Rh\|$

Computer variablesvthat are identical to the terms in Appendix C they represent, are not listed here.

The following sub-programs are included in the program:

1. SUBROUTINE SINUS (X, SC)

   COMPUTER $Si\ (x) = -\int_x^{\infty} \frac{SIN\ t}{t}\ dt$

2. SUBROUTINE KOSINUS (X, CC)

   COMPUTER $Ci(x) = -\int_x^{\infty} \frac{COS\ t}{t}\ dt$

3. FUNCTION CINC (x)

   COMPUTER $\frac{COS\ x}{x}$

4. FUNCTION SINC (x)

   COMPUTER $\frac{SIN\ x}{x}$

5. FUNCTION AKEX (x)

   COMPUTER Ei ($\pm jx$)

6. FUNCTION ADAE (x)

   COMPUTER η_e

7. FUNCTION ZGRAL (x)

   COMPUTER integrand for $\Delta Z_2 = \int (\quad)\ dr$

8. FUNCTION RESIST (s)

   COMPUTER INTEGRAND for $Rij = \int (\quad)\ ds$

9. FUNCTION REACT (s)

   COMPUTER INTEGRAND for $Xij = \int (\quad)\ ds$

```
C     U.S. NAVAL POST GRADUATE SCHOOL COMPUTER LABORATORY
C     COMPUTER GRAPHICS SOLUTION OF ANTENNA PATTERNS
C     DIMENSION PROBLEM AND SET UP GRAPHICS
      COMMON /IMP/ Z0,Y0,L,DLPRI,LMDA,NN,AIRE,K,ADA,COSDL
      REAL K,L,LMDA,KCOS,NORM
      REAL KOS
      REAL KOS1,KOS2,KOS3,KOS4,KOS5,KOS6,KOS7,KOS8
      INTEGER VPAT,PATRN,PAR,E,ANTN
      COMPLEX DLTZ1,DLTZ2,ARGP,ARGM,ARGP2,ARGM2
      COMPLEX ARGU1,ARGU2,CEF,AJ,RVPRI
      COMPLEX ZMUTL
      COMPLEX RHPRI,ZM,Z,Z11,RH,RV,C2
      COMPLEX FIFA,VFAC,HFAC,ADA,ADA1,ADA2,GRAL,Y,ARG1
      COMPLEX SICI,W1,W2,W3,W4,W5
      DIMENSION ITDIR(45),IGDIR(6),IPAR(44),PATRN(362),VPAT(92),MC(44),
     1NW(44),LN(44),IP(44),IFB(44),X1(50),Y1(50),X2(90),Y2(90),X3(360),
     1Y3(360),IMP(362),Z(2),ISAVV(92),ISAVH(362),ITRY(50),IM(50)
      DIMENSION G(2,360),FAC(450)
      DIMENSION X(500),Y(500)
C     PARAMETER FORMAT PROCESSOR
      DATA MC/4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     14,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4/
      DATA L /1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,
     123,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44/
      DATA NW/1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,
     11,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1/
      DATA IP/1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,
     11,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1/
      DATA(IPAR(I),I=2,44,2)/22*77777777B/
      ISIZE=6
      NAMELIST IDEV,IER
      OUTPUT(101)'TYPE IDEV'
      INPUT(101)
      CALL DTINIT(IDEV,ITDIR,45,IER)
      IF(IER.NE.0)OUTPUT(101)IER,'DTINIT'
```

```
ASSIGN 1 TO IFO(1)
ASSIGN 2 TO IFO(2)
ASSIGN 3 TO IFO(3)
ASSIGN 4 TO IFO(4)
ASSIGN 5 TO IFO(5)
ASSIGN 6 TO IFO(6)
ASSIGN 7 TO IFO(7)
ASSIGN 8 TO IFO(8)
ASSIGN 9 TO IFO(9)
ASSIGN 10 TO IFO(10)
ASSIGN 11 TO IFO(11)
ASSIGN 12 TO IFO(12)
ASSIGN 13 TO IFO(13)
ASSIGN 14 TO IFO(14)
ASSIGN 15 TO IFO(15)
ASSIGN 16 TO IFO(16)
ASSIGN 17 TO IFO(17)
ASSIGN 18 TO IFO(18)
ASSIGN 19 TO IFO(19)
ASSIGN 20 TO IFO(20)
ASSIGN 21 TO IFO(21)
ASSIGN 22 TO IFO(22)
ASSIGN 123 TO IFO(23)
ASSIGN 125 TO IFO(25)
ASSIGN 127 TO IFO(27)
ASSIGN 129 TO IFO(29)
ASSIGN 131 TO IFO(31)
ASSIGN 133 TO IFO(33)
ASSIGN 135 TO IFO(35)
ASSIGN 137 TO IFO(37)
ASSIGN 139 TO IFO(39)
ASSIGN 141 TO IFO(41)
ASSIGN 143 TO IFO(43)
ASSIGN 2 TO IFO(24)
ASSIGN 2 TO IFO(26)
```

```
      ASSIGN 2 TO IFP(28)
      ASSIGN 2 TO IFP(30)
      ASSIGN 2 TO IFP(32)
      ASSIGN 2 TO IFP(34)
      ASSIGN 2 TO IFP(36)
      ASSIGN 2 TO IFP(38)
      ASSIGN 2 TO IFP(40)
      ASSIGN 2 TO IFP(42)
      ASSIGN 2 TO IFP(44)
      DO 50 I=1,44
   50 ENCODE(IC(I),IFS(I),IPAR(I))
  170 CONTINUE
      DO 114 I=1,50
  114 IN(I)=0
      DO 111 I=1,50
  111 X1(I)=Y1(I)=0.0
      DO 112 I=1,90
  112 X2(I)=Y2(I)=0.0
      DO 113 I=1,360
  113 X3(I)=Y3(I)=0.0
   ?3 CONTINUE
      DO 51 I=1,43,2
      CALL TEXTB(IDEV,IPAR(I),NW(I),LN(I),IP(I),1,3,IER)
   51 IF(IER.NE.0)OUTPUT(101)IER,'TBLK',I
C     PARAMETER AND OPTIONS COMMAND INPUT PROCESSOR
      DO 52 I=2,44,2
      CALL TEXTR(IDEV,IPAR(I),NW(I),LN(I),IP(I),1,3,IER)
      IF(IER.NE.0)OUTPUT(101)IER,'TBLK',I
      J=22+I/2
   58 IF(MOD(ITSIN(J),2).EQ.0) GO TO 53
      CALL TEXTI(IDEV,IPAR(I),NW(I),LN(I),IP(I),IER)
   52 IF(IER.NE.0)OUTPUT(101)IER,'IPAR',I
    1 FORMAT('ANTE')
    3 FORMAT('LENG')
    5 FORMAT('HGHT')
```

```
      7 FORMAT('PHIP')
      9 FORMAT('THEP')
     11 FORMAT('FREQ')
     13 FORMAT('EPSL')
     15 FORMAT('SGMA')
     17 FORMAT('PHI ')
     19 FORMAT('THET')
     21 FORMAT('PARM')
      2 FORMAT('    ')
      4 FORMAT('    ')
      6 FORMAT('    ')
      8 FORMAT('    ')
     10 FORMAT('    ')
     12 FORMAT('    ')
     14 FORMAT('    ')
     16 FORMAT('    ')
     18 FORMAT('    ')
     20 FORMAT('    ')
     22 FORMAT('    ')
    123 FORMAT('ISTH')
    125 FORMAT('ISTV')
    127 FORMAT('IRCL')
    129 FORMAT('HGTT')
    131 FORMAT('ALPH')
    133 FORMAT('GAIN')
    135 FORMAT('ISEA')
    137 FORMAT('ICRS')
    139 FORMAT('SIGL')
    141 FORMAT('    ')
    143 FORMAT('    ')
     95 FORMAT(F4.0)
     96 FORMAT(F4.1)
     97 FORMAT(F4.2)
     98 FORMAT(F4.3)
    101 FORMAT(I4)
```

```
      DECODE(4,101,IPAR(2))ANTN
      DECODE(4,96,IPAR(4))L
      DECODE(4,96,IPAR(6))H
      DECODE(4,101,IPAR(8))ITEM
      PHIPR=ITEM
      DECODE(4,101,IPAR(10))ITEM
      THEPR=ITEM
      DECODE(4,95,IPAR(12))F
      DECODE(4,96,IPAR(14))EPSLN
      DECODE(4,97,IPAR(16))SIGMA
      DECODE(4,101,IPAR(18))M
      DECODE(4,101,IPAR(20))KAY
      DECODE(4,101,IPAR(22))PAR
      DECODE(4,101,IPAR(24))ISTRH
      DECODE(4,101,IPAR(26))ISTRV
      DECODE(4,101,IPAR(28))IRCAL
      DECODE(4,96,IPAR(30))HT
      DECODE(4,101,IPAR(32))ITEM
      ALPH=ITEM
      DECODE(4,101,IPAR(36))ISEA
      DECODE(4,101,IPAR(38))ICRS
      WRITE(6,3300)ISEA,ICRS
 3300 FORMAT(I4,5X,I4)
      IF(HT.EQ.(1.))SIGMA=SIGMA*.1
      IF(HT.EQ.(2.))SIGMA=SIGMA*.01
      IF(PAR.EQ.1)GO TO 170
      IF(HT.GT.75.0)L=L+100.0
      IF(HT.GT.85.0)L=L+200.0
      CALL DGINIT(IDEV,IGDIR,ISIZE,IER)
      WRITE(6,103)M,KAY,PAR,PHIPR,THEPR,L,H,F,EPSLN,SIGMA
  103 FORMAT(3I5,7F12.8)
      IF(PAR.EQ.1)GO TO 170
C     PATTERN MANUAL ENTRY PROCESSOR
      DO 151 I=1,50
  151 IMD(I)=IM(I)
```

```
      ITRY(1)=IHEAD(0,10)
      ITRY(2)=IPACK(0,.6,0)
      ITRY(3)=IPACK(0,.4,1)
      ITRY(4)=IPACK(-.1,.5,0)
      ITRY(5)=IPACK(.1,.5,1)
      ITRY(6)=IPACK(0,-.6,0)
      ITRY(7)=IPACK(0,-.4,1)
      ITRY(8)=IPACK(-.1,-.5,0)
      ITRY(9)=IPACK(.1,-.5,1)
      ITRY(10)=IPACK(0,0,0)
      DØ 153 I=11,50
      J=I-1
  153 ITRY(I)=IPACK(X1(I),Y1(I),IMD(I))
      CALL GRAPHR(IDEV,ITRY,50,1,IER)
      IF(IER.NE.0)ØUTPUT(101) IER,'GBLK1'
  154 IF(MØD(IGDIR(1),8).EQ.0)GØ TØ 154
      CALL GRAPHI(IDEV,ITRY,1,IER)
      IF(IER.NE.0)ØUTPUT(101)IER,'IGBLK'
      DØ 155 I=1,50
      CALL UNPACK(ITRY(I),X1(I),Y1(I),IMD(I))
  155 IM(I)=IMD(I)
C     ENVØRØNMENTAL CØNSTANTS PRØCESSØR
      PHIPR=PHIPR*(3.14159265/180)
      THEPR=THEPR*(3.14159265/180)
      ALPH=(3.14159265/180)*ALPH
      ALPCM=(3.14159265/2.0)-ALPH
      DLPRI=(3.14159265/2.0)-THEPR
      F=F*1.0E 06
      AØMEG=2*3.14159265*F
      ADA1=CMPLX(0.0,1.26E-06*AØMEG)
      ADA2=CMPLX(SIGMA,AØMEG*EPSLN*8.854E-12)
      ADA=(ADA1/ADA2)**0.5
      TEMP1=REAL(ADA)
      TEMP2=AIMAG(ADA)
      WRITE(6,2400)TEMP1,TEMP2
```

```
 2400 FORMAT('ADA=',2F12.6)
      LMDA=3.0E08/F
      K=6.28318530/LMDA
      F=F*1.0E-06
      C2=K*CMPLX(EPSLN,-1.8E04*SIGMA/F)**0.5
      RHPRI=(K-C2)/(K+C2)
      HTEMP=H
      THTEM=THEPR
      RVPRI=(C2-K)/(C2+K)
      JJJ=0
      II=0
      DPHIP=0.0
      IF(ISEA.GT.0)GO TO 3000
 3010 CONTINUE
C     INPUT RESISTANCE PROCESSOR
      IF(ANTN.EQ.1)GO TO 1100
      IF(ANTN.EQ.2)GO TO 1200
      IF(ANTN.EQ.3)GO TO 1300
      IF(ANTN.EQ.4)GO TO 1400
      IF(ANTN.EQ.5)GO TO 1500
      IF(ANTN.EQ.6)GO TO 1600
      IF(ANTN.EQ.7)GO TO 1700
      IF(ANTN.EQ.8)GO TO 1800
 2000 CONTINUE
      IF(ISEA.GT.0)GO TO 3013
      WRITE(6,104)RIN
 3013 CONTINUE
  104 FORMAT(F12.4)
C     OBSERVATION ANGLE CONSTANTS PROCESSOR
      DO 42 N=1,2
      IF(N.EQ.1) GO TO 71
      IF(N.EQ.2) GO TO 72
   71 DO 42 I=1,90
      J=M
      E=I
```

```
      GØ TØ 73
   72 DØ 42 J=1,360
      I=KAY
      E=J
      GØ TØ 73
   73 CØNTINUE
      THETA=I*(3.14159265/180)
      PHI=J*(3.14159265/180)
      KØS=CØS(THETA)*CØS(THEPR)+SIN(THETA)*SIN(THEPR)*CØS(PHI-PHIPR)
      SINSQ=1-(KØS**2)
      WOSQ=(3.14159265/180)**2
      IF(SINSQ.LT.WOSQ)SINSQ=WOSG
      FIFA=(1-((K/C2)*SIN(THETA))**2)**0.5
      KCØS=CØS(THETA)
      RV=(KCØS-(K/C2)*FIFA)/(KCØS+(K/C2)*FIFA)
      RH=(KCØS-(C2/K)*FIFA)/(KCØS+(C2/K)*FIFA)
      VR=REAL(RV)
      VI=AIMAG(RV)
      SIGHV=ATAN2(VI,VR)
      HR=REAL(RH)
      HI=AIMAG(RH)
      SIGHH=ATAN2(HI,HR)
C     GAIN PRØCESSØR
      IF[ANTN.EQ.1]GØ TØ 100
      IF(ANTN.EQ.2)GØ TØ 200
      IF(ANTN.EQ.3)GØ TØ 300
      IF(ANTN.EQ.4)GØ TØ 400
      IF(ANTN.EQ.5)GØ TØ 500
      IF(ANTN.EQ.6)GØ TØ 600
      IF(ANTN.EQ.7)GØ TØ 700
      IF(ANTN.EQ.8)GØ TØ 800
   42 CØNTINUE
C     NØRMALIZE AND MAX GAIN PRØCESSØR
      N=1
      DØ 43 J=1,2
```

```
      IF(J.EQ.1) GO TO 75
      IF(J.EQ.2) GO TO 76
   75 DO 43 I=1,90
      GO TO 77
   76 DO 43 I=1,360
      GO TO 77
   77 CONTINUE
      FAC(N)=G(J,I)
   43 N=N+1
      NORM=0.0
      DO 46 I=1,450
   46 NORM=AMAX1(NORM,FAC(I))
      GAIN=NORM/RIN
      ATEMP=ALOG10(GAIN)
      ENCODE(4,96,IPAR(34))ATEMP
      CALL TEXTO(IDEV,IPAR(34),1,34,1,1,3,IER)
      IF(IER.NE.0)OUTPUT(101)IER,'GAIN'
      IF(ISEA.GT.0)GO TO 3020
      GAIN=10.*ATEMP
      IF(PAR.EQ.2)GO TO 171
  181 CONTINUE
      WRITE(6,106)NORM,GAIN
  106 FORMAT(2F12.6)
 3021 CONTINUE
C     PATTERN DISPLAY PROCESSOR
      DO 44 I=1,360
      PHI=I*(3.14159265/180)
      G(2,I)=G(2,I)/(NORM*2.0)
      X(I)=G(2,I)*COS(PHI)
   44 Y(I)=G(2,I)*SIN(PHI)+0.5
      IMD(1)=0
      DO 45 I=2,360
   45 IMD(I)=1
      PATRN(1)=IHEAD(0,10)
      DO 47 I=2,361
```

```
      J=I-1
   47 PATRN(I)=IPACK(X(J),Y(J),IMD(J))
      PATRN(362)=0
      IF(ISEA.GT.0)GØ TØ 3030
      CALL GRAPHR(IDEV,PATRN,362,2,IER)
      IF(IER.NE.0)ØUTPUT(101)IER,'GBLK'
   60 IF(MØD(IGDIR(2),8).EQ.0)GØ TØ 60
 3011 CØNTINUE
      IF(ISTRH.EQ.1) GØ TØ 156
  158 CØNTINUE
C     DISPLAY VERT PATTERN AT REQUESTED PHI
      DØ 49 I=1,90
      THETA=I*(3.14159265/180)
      G(1,I)=G(1,I)/(NØRM*2.0)
      X(I)=G(1,I)*SIN(THETA)
   49 Y(I)=G(1,I)*CØS(THETA)-0.5
      IMD(1)=0
      DØ 61 I=2,90
   61 IMD(I)=1
      VPAT(1)=IHEAD(0,10)
      DØ 62 I=2,91
      J=I-1
   62 VPAT(I)=IPACK(X(J),Y(J),IMD(J))
      VPAT(92)=0
      IF(ISEA.GT.0)GØ TØ 3040
      CALL GRAPHR(IDEV,VPAT,92,3,IER)
      IF(IER.NE.0) ØUTPUT(101)IER,'GBLK2'
   64 IF(MØD(IGDIR(3),8).EQ.0)GØ TØ 64
 3012 CØNTINUE
      IF(ISTRV.EQ.1)GØ TØ 159
  161 CØNTINUE
      IF(IRCAL.EQ.1)GØ TØ 162
      IF(ISEA.GT.0)GØ TØ 3000
      GØ TØ 33
C     PATTERN SAVE PRØCESSØR
```

```
156 CALL GRAPHI(IDEV,PATRN,2,IER)
    IF(IER.NE.0)ØUTPUT(101)IER,'GBLK2'
    DØ 157 I=1,360
157 CALL UNPACK(PATRN(I+1),X3(I),Y3(I),IMD(I))
    GØ TØ 158
159 CALL GRAPHI(IDEV,VPAT,3,IER)
    IF(IER.NE.0)ØUTPUT(101)IER,'GBLK3'
    DØ 160 I=1,90
160 CALL UNPACK(VPAT(I+1),X2(I),Y2(I),IMD(I))
    GØ TØ 161
C   DISPLAY SAVED PATTERNS PRØCESSØR
162 IMD(1)=0
    ISAVH(1)=IHEAD(0,10)
    DØ 163 I=2,360
163 IMD(I)=1
    DØ 164 I=2,361
    J=I-1
164 ISAVH(I)=IPACK(X3(J),Y3(J),IMD(J))
    ISAVH(362)=0
    CALL GRAPHR(IDEV,ISAVH,362,4,IER)
    IF(IER.NE.0)ØUTPUT(101)IER,'GBLK4'
166 IF(MØD(IGDIR(4),8).EQ.0)GØ TØ 166
    ISAVV(1)=IHEAD(0,10)
    DØ 167 I=2,91
    J=I-1
167 ISAVV(I)=IPACK(X2(J),Y2(J),IMD(J))
    ISAVV(92)=0
    CALL GRAPHR(IDEV,ISAVV,92,5,IER)
    IF(IER.NE.0)ØUTPUT(101)IER,'GBLK5'
169 IF(MØD(IGDIR(5),8).EQ.0)GØ TØ 169
    GØ TØ 33
C   LØG GAIN PRØCESSØR
171 BLIM=.001
    DØ 172 I=1,90
    TEMP=G(1,I)/NØRM
```

```
      IF(TEMP.LT.BLIM)TEMP=BLIM
      G(1,I)=ALOG10(TEMP)+3.0
  172 CONTINUE
      DO 173 I=1,360
      TEMP=G(2,I)/NORM
      IF(TEMP.LT.BLIM)TEMP=BLIM
      G(2,I)=ALOG10(TEMP)+3.0
  173 CONTINUE
  190 FORMAT(2F12.8,I5)
      NORM=3.0
      GO TO 181
 3000 II=II+1
      II=MOD(II,36)
      PI=3.14159265
      D2R=PI/180.0
      VAR=(PI/18.0)*II
      WAVE=(ISEA*8*SIN(VAR))*D2R
      VAR1=ICRS*D2R
      DLT1=WAVE*SIN(VAR1)
      DLT2=WAVE*COS(VAR1)*0.3
      IF(ANTN.EQ.5)GO TO 3500
      H=HTEMP*COS(DLT1)*COS(DLT2)
      THEPR=THTEM-DLT1
      DLPRI=PI/2.-THEPR
      GO TO 3090
 3500 AA=2*L*SIN(DLT1/2.)
      BB=2*L*SIN(DLT2/2.)
      CC=SQRT(AA**2+BB**2)
      DD=SQRT(L**2-(CC/2.)**2)
      DLT3=2.*ATAN2((CC/2.),DD)
      SIND3=SIN(DLT3)
      IF((SIND3.LT.WOSQ).AND.(SIND3.GE.0.0))SIND3=WOSQ
      IF((SIND3.GT.-WOSQ).AND.(SIND3.LT.0.0))SIND3=-WOSQ
      SINA=SIN(DLT1)/SIND3
      SINA=ABS(SINA)
```

```
      COSA=SQRT(1.0-SINA**2)
      DPHIP=ATAN2(SINA,COSA)
      IF((DLT1.LT.0.0).AND.(DLT2.GE.0.0))DPHIP=-DPHIP
      IF((DLT1.LT.0.0).AND.(DLT2.LT.0.0))DPHIP=-(PI-DPHIP)
      IF((DLT1.GT.0.0).AND.(DLT2.LT.0.0))DPHIP=PI-DPHIP
      THEPR=THTEM+DLT3
      DLPRI=PI/2.-THEPR
 3090 JJJ=JJJ+1
      IF(JJJ.EQ.37)GO TO 33
      WRITE(6,3301)DLT1,DLT2,DLT3,WAVE,H,II
 3301 FORMAT(5F12.6,I4)
      GO TO 3010
 3020 TEMP=G(1,KAY)/RIN
      SIGL=ALOG10(TEMP)
      ENCODE(4,96,IPAR(40))SIGL
      CALL TEXTO(IDEV,IPAR(40),1,40,1,1,3,IER)
      IF(IER.NE.0)OUTPUT(101)IER,'SIGL'
      SIG=10*SIGL
      WRITE(6,3022)SIG,RIN
 3022 FORMAT(F12.6,5X,F12.6)
      GO TO 3021
 3030 CALL GRAPHO(IDEV,PATRN,362,2,IER)
      IF(IER.NE.0)OUTPUT(101)IER,'HPAT'
      GO TO 3011
 3040 CALL GRAPHO(IDEV,VPAT,92,3,IER)
      IF(IER.NE.0)OUTPUT(101)IER,'VPAT'
      GO TO 3012
C     ARBITRARILY TILTED DIPOLE
  100 DELTA=(3.14159265/2.-THETA)
      S1=COS(SIGHH-2*K*H*SIN(DELTA))
      S2=SIN(SIGHH-2*K*H*SIN(DELTA))
      S3=COS(SIGHV-2*K*H*SIN(DELTA))
      S4=SIN(SIGHV-2*K*H*SIN(DELTA))
      CV=CABS(RV)
      CH=CABS(RH)
```

```
      COSDL=COS(DELTA)
      SINDL=SIN(DELTA)
      SINDP=SIN(DLPRI)
      COSDP=COS(DLPRI)
      SINPI=SIN(PHI-PHIPR)
      COSPI=COS(PHI-PHIPR)
      FCT=1.0-(SINDL*SINDP+COSDL*COSDP*SINPI)**2
      FCTR=1.0-(-SINDP*SINDL+COSDL*COSDP*SINPI)**2
      GI=(COS(0.5*K*L*(SINDL*SINDP+COSDL*COSDP*SINPI))-COS(0.5*K*L))/FCT
      DI=(COS(0.5*K*L*(COSDL*COSDP*SINPI-SINDL*SINDP))-COS(0.5*K*L))/
     1FCTR
      ETHT1=(COSDP*SINPI*SINDL-SINDP*COSDL)*GI-(COSDP*SINPI*SINDL+
     1SINDP*COSDL)*DI*CV*S3
      EPHI1=COSDP*COSPI*(GI+DI*CH*S1)
      ETHT2=(COSDP*SINPI*SINDL+SINDP*COSDL)*DI*CV*S4
      EPHI2=COSDP*COSPI*DI*CH*S2
      IF(FCT.LT.WOSQ)ETHT1=EPHI1=0.0
      IF(FCTR.LT.WOSQ)ETHT2=EPHI2=0.0
      G(N,E)=120.*(ETHT1**2+ETHT2**2+EPHI1**2+EPHI2**2)
      GO TO 42
 1100 SAVIT=DLPRI
      DO 1110 I=1,2
      YO=.00001
      ZO=0.0
      IF(I.EQ.1)DLPRI=0.0
      IF(I.EQ.2)DLPRI=SAVIT
      IF(I.EQ.2)YO=2.*H*COS(DLPRI)/LMDA
      S=-0.5*L/LMDA
      RGRAL=RESIST(S)/2
      DS=L/(LMDA*100)
      DO 1115 N=2,100
      S=S+DS
 1115 RGRAL=RESIST(S)+RGRAL
      RGRAL=-30.0*(RGRAL+(RESIST(0.5*L/LMDA))/2.)*DS
      S=-0.5*L/LMDA
```

```
      XGRAL=REACT(S)/2.
      DO 1116 N=2,100
      S=S+DS
 1116 XGRAL=XGRAL+REACT(S)
      XGRAL=-30.0*(XGRAL+(REACT(0.5*L/LMDA))/2)*DS
 1110 Z(I)=CMPLX(RGRAL,XGRAL)
      AJ=CMPLX(0,1)
      ONE=COS(DLPRI)
      TWO=-SIN(DLPRI)
      CEE=(RHPRI*COS(DLPRI)+AJ*RVPRI*SIN(DLPRI))*CMPLX(ONE,TWO)
      RIN=REAL(Z(1))+REAL(Z(2)*CEE)
      GO TO 2000
 1500 CALL SINUS((2*K*L),SC)
      SI1=-SC
      CALL KOSINUS((2*K*L),CC)
      CI1=CC
      CALL KOSINUS((4*K*L),CC)
      CI2=CC
      CALL SINUS((4*K*L),SC)
      SI2=-SC
      RIN=30.0*(0.5*(ALOG(K*L)+0.577-CI2)+.693+COS(K*L)*(COS(K*L)*
     1(ALOG(K*L)+.577-2*CI1+CI2)-SIN(K*L)*(SI2-2.*SI1)))
      GO TO 2000
C     VERTICAL MONOPOLE
C     VERTICAL MONOPOLE GAIN
  200 DELTA=3.14159264/2.-THETA
      SINDL=SIN(DELTA)
      COSDL=COS(DELTA)
      CV=CABS(RV)
      S3=COS(SIGHV)
      S4=SIN(SIGHV)
      A=COS(K*L*SINDL)-COS(K*L)
      B=SIN(K*L*SINDL)-SINDL*SIN(K*L)
      G(N,E)=(30.0/COSDL**2)*((A*(1.+CV*S3)+B*CV*S4)**2+
     1(B*(1.-CV*S3)+A*CV*S4)**2)
```

```
      GØ TØ 42
C     VERTICAL MØNØPØLE
 1200 CALL KØSINUS((4*K*L),CC)
      CIN2=ALØG(4*K*L)+.577-CC
      CALL KØSINUS((2*K*L),CC)
      CIN1=ALØG(2*K*L)+.577-CC
      CALL SINUS((4*K*L),SC)
      SIN2=1.57078633+SC
      CALL SINUS((2*K*L),SC)
      SIN1=1.57078633+SC
      RIN=15.*((2.+2*CØS(2*K*L))*CIN1-CØS(2*K*L)*CIN2-2*SIN(2*K*L)*SIN1+
     1SIN(2*K*L)*SIN2)
      GØ TØ 2000
C     VERTICAL MØNØPØLE WITH GRØUND SCREEN
  300 DELTA=3.14159265/2.-THETA
      IF((N.EQ.2).AND.(J.GT.1))GØ TØ 310
      SINDL=SIN(DELTA)
      CØSDL=CØS(DELTA)
      CV=CABS(RV)
      S3=CØS(SIGHV)
      S4=SIN(SIGHV)
      A=CØS(K*L*SINDL)-CØS(K*L)
      B=SIN(K*L*SINDL)-SINDL*SIN(K*L)
      C1=SIN(K*L)
      IF((C1.LT.WOSQ).AND.(C1.GE.0.0))C1=WOSQ
      IF((C1.GT.-WOSQ).AND.(C1.LT.0.0))C1=-WOSQ
      C3=A
      IF((C3.LT.WOSQ).AND.(C3.GE.0.0))C3=WOSQ
      IF((C3.GT.-WOSQ).AND.(C3.LT.0.0))C3=-WOSQ
      XB=K*H
      DX=XB/100
      XX=C
      GRAL=PTGRL(XX)/2
      DØ 315 II=2,100
      XX=XX+DX
```

```
  315 GRAL=GRAL+PTGRL(XX)
      GRAL=(GRAL+PTGRL(XB)/2)*DX
      GRAL=1.0-(ADA*SIN(THETA)*GRAL)/120.*3.14159265*C1*C3
      SRFAC=(CABS(GRAL))**2
      WRITE(6,311)SRFAC
  311 FØRMAT('SRFAC=',F12.6)
  310 CØNTINUE
      G(N,E)=(30.0/CØSDL**2)*((A*(1.+CV*S3)+B*CV*S4)**2+
     1(B*(1.-CV*S3)+A*CV*S4)**2)*SRFAC/C1**2
      GØ TØ 42
C     GRØUND SCREEN
 1300 C1=SIN(K*L)**2
      IF(C1.LT.WOSQ)C1=WOSQ
      RO=(H**2+L**2)**0.5
      R1=H+RO
      ARGP=CMPLX(0.0,K*L)
      ARGM=CMPLX(0.0,-K*L)
      ARGP2=CMPLX(0.0,2*K*L)
      ARGM2=CMPLX(0.0,-2*K*L)
      DLTZ1=(ADA/4*3.14159265*C1)*(CEXP(ARGP2)*AKEX(-2*K*(RO+L))+
     1CEXP(ARGM2)*AKEX(-2*K*(RO-L))+2*CØS(K*L)**2*AKEX(-2*K*H)+
     14*CØS(K*L)*AKEX(-K*R1)-4*CØS(K*L)*CEXP(ARGM)*AKEX(-K*(R1-L))-
     14*CØS(K*L)*CEXP(ARGP)*AKEX(-K*(R1+L)))
      WRITE(6,1311)DLTZ1
 1311 FØRMAT('DLTZ1=',F12.6)
      NN=120
      WIRE=.01
      DX=(H-.01)/100
      DUM=.01
      DLTZ2=ZGRAL(DUM)/2.
      DØ 1310 II=2,100
      DUM=DUM+DX
 1310 DLTZ2=DLTZ2+ZGRAL(DUM)
      DLTZ2=(DLTZ2+ZGRAL(H)/2.)*DX
      DLTZ2=-DLTZ2
```

```
      WRITE(6,1312)DLTZ2
 1312 FØRMAT('DLTZ2=',F12.6)
      CALL KØSINUS((4*K*L),CC)
      CIN2=ALØG(4*K*L)+.577-CC
      CALL KØSINUS((2*K*L),CC)
      CIN1=ALØG(2*K*L)+.577-CC
      CALL SINUS((4*K*L),SC)
      SIN2=1.57078633+SC
      CALL SINUS((2*K*L),SC)
      SIN1=1.57078633+SC
      RIN=15.*((2.+2*CØS(2*K*L))*CIN1-CØS(2*K*L)*CIN2-2*SIN(2*K*L)*SIN1
     1+SIN(2*K*L)*SIN2)
      RIN=RIN+REAL(DLTZ1+DLTZ2)
      GØ TØ 2000
C     INVERTED L
  400 DELTA=(3.14159265/2.)-THETA
      SINDL=SIN(DELTA)
      CØSDL=CØS(DELTA)
      CV=CABS(RV)
      CH=CABS(RH)
      DENM1=1.0-CØSDL**2*SIN(PHI)**2
      S1=CØS(SIGHH-2*K*H*SINDL)
      S2=SIN(SIGHH-2*K*H*SINDL)
      S3=CØS(SIGHV-2*K*H*SINDL)
      S4=SIN(SIGHV-2*K*H*SINDL)
      A=CØS(K*L)*CØS(K*H*SINDL)-SINDL*SIN(K*L)*SIN(K*H*SINDL)
     1-CØS(K*(H+L))
      B=SINDL*SIN(K*L)*CØS(K*H*SINDL)+CØS(K*L)*SIN(K*H*SINDL)
     1-SINDL*SIN(K*(H+L))
      GI=SIN(K*L*CØSDL*SIN(PHI))-CØSDL*CØS(PHI)*SIN(K*L)
      GR=CØS(K*L*CØSDL*SIN(PHI))-CØS(K*L)
      ETHET=((SIN(PHI)*SINDL*(GR*(1.0-CV*S3)+GI*CV*S4)/DENM1)
     1-(A*(1.0+CV*CØS(SIGHV))+B*CV*SIN(SIGHV))/CØSDL)**2
     1+((SIN(PHI)*SINDL*(GI*(1.0-CV*S3)-GR*CV*S4)/DENM1)
     1-(B*(1.0-CV*CØS(SIGHV))+A*CV*SIN(SIGHV))/CØSDL)**2
```

```
      EPHI=(COS(PHI)/DENM1)**2*((GR*(1.0+CH*S1)-GI*CH*S2)**2
     1+(GI*(1.0+CH*S1)+GR*CH*S2)**2)
      G(N,E)=30.0*(ETHET+EPHI)
      GO TO 42
C     INVERTED L
 1400 CALL KOSINUS((2*K*H),CC)
      CI1=CC
      CALL KOSINUS((4*K*H),CC)
      CI2=CC
      CALL SINUS((2*K*H),SC)
      SI1=-SC
      CALL SINUS((4*K*H),SC)
      SI2=-SC
      RIN=60.*(1.41+ALOG(2*L/LMDA)+SINC(2*K*L))+30.*(-0.5*COS(2*K*H)*
     1(ALOG(2*K*H)+1.270+CI2)+(1.0+COS(2*K*H))*(ALOG(2*K*H)+0.577-CI1)-
     1SIN(2*K*H)*(0.5*SI2-SI1))
      GO TO 2000
C     SLOPING LONG WIRE
C     SLOPE LONGWIRE
  500 DELTA=3.14159265/2.0-THETA
      PHI=PHI-DPHIP
      COSDL=COS(DELTA)
      SINDL=SIN(DELTA)
      COSDP=COS(DLPRI)
      SINDP=SIN(DLPRI)
      COSPI=COS(PHI)
      SINPI=SIN(PHI)
      FCT1=1.0-(SINDL*SINDP+COSDL*COSDP*COSPI)**2
      FCT2=1.0-(COSDL*COSDP*COSPI-SINDL*SINDP)**2
      CIG=(COS(K*L*(SINDL*SINDP+COSDL*COSDP*COSPI))-COS(K*L))/FCT1
      SIG=(SIN(K*L*(SINDL*SINDP+COSDL*COSDP*COSPI))-
     1(SINDL*SINDP+COSDL*COSDP*COSPI)*SIN(K*L))/FCT1
      CIGP=(COS(K*L*(COSDL*COSDP*COSPI-SINDL*SINDP))-COS(K*L))/FCT2
      SIGP=(SIN(K*L*(COSDL*COSDP*COSPI-SINDL*SINDP))+
     1(SINDL*SINDP-COSDL*COSDP*COSPI)*SIN(K*L))/FCT2
```

```
      CH=CABS(RH)
      CV=CABS(RV)
      EPHI1=-CØSDP*SINPI*(CIG+CH*(CIGP*CØS(SIGHH)-SIGP*SIN(SIGHH)))
      EPHI2=-CØSDP*SINPI*(SIG+CH*(CIGP*SIN(SIGHH)+SIGP*CØS(SIGHH)))
      ETHT1=CIG*(CØSDP*CØSPI*SINDL-SINDP*CØSDL)-CV*(CØSDP*CØSPI*SINDL+
     1SINDP*CØSDL)*(CIGP*CØS(SIGHV)-SIGP*SIN(SIGHV))
      ETHT2=SIG*(CØSDP*CØSPI*SINDL-SINDP*CØSDL)-CV*(CØSDP*CØSPI*SINDL+
     1SINDP*CØSDL)*(CIGP*SIN(SIGHV)+SIGP*CØS(SIGHV))
      IF(FCT1.LT.WOSQ)ETHT1=ETHT2=EPHI1=EPHI2=0.0
      G(N,E)=30.0*(EPHI1**2+EPHI2**2+ETHT1**2+ETHT2**2)
      IF((FCT1.LT.WOSG).AND.(FCT2.LT.WOSQ))G(N,E)=0.1
      GØ TØ 42
C     SLØPING VEE
  600 DELTA=(3.14159265/2.0)-THETA
      SINDL=SIN(DELTA)
      SINDP=SIN(DLPRI)
      CØSDL=CØS(DELTA)
      CØSDP=CØS(DLPRI)
      ADJ=CØS(ALPH)*CØSDP
      ØPP=SIN(ALPH)
      ALPH=ATAN2(ØPP,ADJ)
      CØSP=CØS(PHI+ALPH)
      CØSM=CØS(PHI-ALPH)
      KØS1=SINDL*SINDP+CØSDL*CØSDP*CØSM
      KØS2=SINDL*SINDP+CØSDL*CØSDP*CØSP
      KØS3=-SINDL*SINDP+CØSDL*CØSDP*CØSM
      KØS4=-SINDL*SINDP+CØSDL*CØSDP*CØSP
      KØS5=CØSDL*SINDP+SINDL*CØSDP*CØSM
      KØS6=CØSDL*SINDP+SINDL*CØSDP*CØSP
      KØS7=-CØSDL*SINDP+SINDL*CØSDP*CØSM
      KØS8=-CØSDL*SINDP+SINDL*CØSDP*CØSP
      U1=K*L*(1.0-KØS1)
      U2=K*L*(1.0-KØS2)
      U3=K*L*(1.0-KØS3)
      U4=K*L*(1.0-KØS4)
```

```
      S1=COS(SIGHH-2*K*H*SINDL)
      S2=SIN(SIGHH-2*K*H*SINDL)
      S3=COS(SIGHV-2*K*H*SINDL)
      S4=SIN(SIGHV-2*K*H*SINDL)
      COSU1=COS(U1)
      COSU2=COS(U2)
      COSU3=COS(U3)
      COSU4=COS(U4)
      SINU1=SIN(U1)
      SINU2=SIN(U2)
      SINU3=SIN(U3)
      SINU4=SIN(U4)
      A=(KOS7*(COSU1-1.)/U1-KOS8*(COSU2-1.)/U2)+CABS(RV)*((KOS6*(
     1(COSU4-1.)*S3+SINU4*S4)/U4)-KOS5*((COSU3-1.)*S3+SINU3*S4)/U3)
      B=(KOS8*SINU2/U2-KOS7*SINU1/U1)+CABS(RV)*(KOS5*(SINU3*S3-(COSU3-1.
     1)*S4)/U3+KOS6*((COSU4-1.)*S4-SINU4*S3)/U4)
      C=SIN(PHI+ALPH)*(COSU2-1.)/U2-SIN(PHI-ALPH)*(COSU1-1.)/U1
     1+CABS(RH)*((SIN(PHI+ALPH)*(COSU4-1.)/U4-SIN(PHI-ALPH)*(COSU3-1.)
     1/U3)*S1-(SIN(PHI-ALPH)*SINU3/U3-SIN(PHI+ALPH)*SINU4/U4)*S2)
      D=SIN(PHI-ALPH)*SINU1/U1-SIN(PHI+ALPH)*SINU2/U2+CABS(RH)*((SIN(PHI
     1-ALPH)*SINU3/U3-SIN(PHI+ALPH)*SINU4/U4)*S1+(SIN(PHI+ALPH)*
     1(COSU4-1.)/U4-SIN(PHI-ALPH)*(COSU3-1.)/U3)*S2)
      G(N,E)=0.05*(A**2+B**2+COSDP**2*(C**2+D**2))
      GO TO 42
C     TILTED INVERTED V
 1600 RIN=1.0
      GO TO 2000
C     HORIZONTAL RHOMBIC
  700 DELTA=(3.14159265/2.0)-THETA
      SINDL=SIN(DELTA)
      COSDL=COS(DELTA)
      SINAC=SIN(ALPCM)
      COSAC=COS(ALPCM)
      COSPI=COS(PHI)
      SINPI=SIN(PHI)
```

```
      S1=CØS(SIGHH-2*K*H*SINDL)
      S3=CØS(SIGHV-2*K*H*SINDL)
      U1=1.0-CØSDL*(SINAC*CØSPI+CØSAC*SINPI)
      U2=1.0-CØSDL*(SINAC*CØSPI-CØSAC*SINPI)
      G(N,E)=2.16*((CØSAC*SIN(K*0.5*L*U1)*SIN(K*0.5*L*U2)/(U1*U2))**2)*
     1(((CØSPI-SINAC*CØSDL)**2)*((CABS(RH))**2+1.0+2.0*(CABS(RH))*S1)+
     1(SINDL**2)*(SINPI**2)*((CABS(RV))**2+1.0-2.0*(CABS(RV))*S3))
      GØ TØ 42
C     HØRIZØNTAL RHØMBIC
 1700 RIN=1.0
      GØ TØ 2000
C     VERTICAL HALF RHØMBIC
  800 DELTA=(3.14159265/2.0)-THETA
      CØSDL=CØS(DELTA)
      SINDL=SIN(DELTA)
      CØSAC=CØS(ALPCM)
      SINAC=SIN(ALPCM)
      CØSPI=CØS(PHI)
      SINPI=SIN(PHI)
      FACK1=1.0-CØSDL*CØSAC*CØSPI-SINDL*SINAC
      FACK2=1.0-CØSDL*CØSAC*CØSPI+SINDL*SINAC
      UU1=CØS(SIGHH-2*K*H*SINDL)
      UU2=SIN(SIGHH-2*K*H*SINDL)
      UU3=CØS(SIGHV-2*K*H*SINDL)
      UU4=SIN(SIGHV-2*K*H*SINDL)
      S1=SIN(K*L*FACK1)
      CE1=CØS(K*L*FACK1)
      S2=SIN(K*L*FACK2)
      CE2=CØS(K*L*FACK2)
      R1=(1.0-CE1)/FACK1
      AI1=S1/FACK1
      R2=(CE1*(1.0-CE2)+S1*S2)/FACK2
      AI2=(CE1*S2-S1*(1.0-CE2))/FACK2
      R3=(1.0-CE1)*CØS(2*K*L*SINAC*SINDL)-(1.0-CE1)*SIN(2*K*L*SINAC
     1*SINDL)
```

```
      F1=(AI3*CE1-R3*S1)/FACK1
      F2=(R3*CE1+AI3*S1)/FACK1
      F3=(1.0-CE2)/FACK2
      F4=S2/FACK2
      RB=R1+R2+CABS(RV)*((F2+F3)*UU3-(F1+F4)*UU4)
      BI=AI1+AI2-CABS(RV)*((F2+F3)*UU4+(F1+F4)*UU3)
      RC=R2-R1+CABS(RV)*((F2-F3)*UU3-(F1-F4)*UU4)
      CC=AI2-AI1+CABS(RV)*((F2-F3)*UU4+(F1-F4)*UU3)
      RA=R1+R2+CABS(RH)*((F2+F3)*UU1+(F1+F4)*UU2)
      A1=AI1+AI2+CABS(RH)*((F2+F3)*UU2+(F1+F4)*UU1)
      G(N,E)=0.1*((RB*COSAC*COSPI*SINDL+RC*SINAC*COSDL)**2
     1+(BI*COSAC*COSPI*SINDL+CC*SINAC*COSDL)**2+(RA*COSAC*SINPI)**2
     1+(A1*COSAC*SINPI)**2)
      GO TO 42
C     VERTICAL HALF RHOMBIC
 1800 RIN=1.0
      GO TO 2000
      END
```

```
      SUBRØUTINE SINUS(X,SC)
      IF(X.GE.10.0)GØ TØ 10
      DX=X/100
      GRAL=0.5
      XA=0.0
      DØ 100 I=2,100
      XA=XA+DX
  100 GRAL=GRAL+SINC(XA)
      GRAL=(GRAL+SINC(X)/2.)*DX
      SC=-3.14159265/2.+GRAL
      GØ TØ 20
   10 SC=-CØS(X)/X
   20 CØNTINUE
      RETURN
      END
```

```
      SUBROUTINE KOSINUS(X,CC)
      IF(X.GE.10.0)GO TO 10
      DX=X/100
      GRAL=0.0
      XA=0.0
      DO 100 I=2,100
      XA=XA+DX
  100 GRAL=GRAL+(1.0-COS(XA))/XA
      GRAL=(GRAL+(1.0-COS(X))/2*X)*DX
      CC=ALOG(1.781072*X)-GRAL
      GO TO 20
   10 CC=SIN(X)/X
   20 CONTINUE
      RETURN
      END
```

```
FUNCTIØN CINC(X)
CINC=CØS(X)/X
RETURN
END
```

```
FUNCTION SINC(X)
SINC=SIN(X)/X
RETURN
END
```

```
      FUNCTION ZGRAL(X)
C REQUIRED FOR VERTICAL WHIP WITH GROUND SCREEN
      COMPLEX ZGRAL
      COMPLEX ARG1,ARG2
      REAL L,LMDA,K
      COMPLEX ADA,ADAE
      COMMON /IMP/ ZO,YO,L,DLPRI,LMDA,NN,WIRE,K,ADA,COSDL
      ARG1=CMPLX(0.0,-K*(X**2+L**2)**0.5)
      ARG2=CMPLX(0.0,-K*X)
      C1=SIN(K*L)**2
      IF(C1.LT.0.01)C1=.01
      XX=(240.*3.14159265**2*X/(NN*LMDA))*ALOG(X/(NN*WIRE))
      ADAE=CMPLX(0.0,XX)
      ZGRAL=(ADA*ADAE/(ADA+ADAE))*((CEXP(ARG1)-CEXP(ARG2)*COS(K*L))/
     1(2*3.14159265*C1*X))
      TEMP1=AIMAG(ADAE)
      TEMP2=REAL(ZGRAL)
      TEMP3=AIMAG(ZGRAL)
      WRITE(6,10)NN,K,WIRE,TEMP1,TEMP2,TEMP3
   10 FORMAT('ZGRAL',6F12.6)
      RETURN
      END
```

```
      FUNCTIØN PTGRL(X)
C     REQUIRED FØR VERTICAL WHIP WITH GRØUND SCREEN
      CØMPLEX PTGRL
      CØMMØN /IMP/ Z0,Y0,L,DLPRI,LMDA,NN,WIRE,K,ADA,CØSDL
      CØMPLEX ADA
      REAL L,LMDA,K
      CØMPLEX ARG1,ARG2
      S=X*CØSDL
      PI=3.14159265
      IF(S.LE.1)GØ TØ 20
      P1=1+15/(2*(8*S)**2)-(225.*7*9)/(24*(8*S)**4)+(225.*49*81*143)/
     1(720*(8*S)**6)
      Q1=3/(8*S)-315/(6*(8*S)**3)+(9*35*35*99)/(120*(8*S)**6)
      AJ1=(2./(PI*S))**0.5*(P1*CØS(S-3*PI/4)-Q1*SIN(S-3*PI/4))
      GØ TØ 30
   20 CØNTINUE
      AJ1=S/2-S**3/16+S**5/384-S**7/(128*144)+S**9/(512*24*120)
   30 CØNTINUE
      Z=(X**2+K**2*L**2)**0.5
      ARG1=CMPLX(0.0,-Z)
      ARG2=CMPLX(0.0,-X)
      PTGRL=(CEXP(ARG1)-CEXP(ARG2)*CØS(K*L))*AJ1
      RETURN
      END
```

```
      FUNCTIØN AKEX(X)
C REQUIRED FØR VERTICAL WHIP WITH GRØUND SCREEN
      CØMPLEX AKEX
      XX=ABS(X)
      CALL KØSINUS(XX,CC)
      CALL SINUS(XX,SC)
      IF(X.LT.0.0)AKEX=CMPLX(CC,-SC)
      IF(X.GE.0.0)AKEX=CMPLX(CC,SC)
      RETURN
      END
```

```
C REQUIRED FOR DIPOLE
      FUNCTION RESIST(S)
      REAL L,LMDA,K
      COMPLEX ADA
      COMMON /IMP/ ZO,YO,L,DLPRI,LMDA,NN,WIRE,K,ADA,COSDL
      PI=3.14159265
      SZ=S*COS(2*DLPRI)
      SY=-S*SIN(2*DLPRI)
      TERM=YO+SY
      ROW2=(YO+SY)**2
      CA=ZO+SZ
      CA1=CA+0.5*L/LMDA
      CA2=CA-0.5*L/LMDA
      R=SQRT(ROW2+CA**2)
      R1=SQRT(ROW2+CA1**2)
      R2=SQRT(ROW2+CA2**2)
      SR=SIN(2*PI*R)/R
      SR1=SIN(2*PI*R1)/R1
      SR2=SIN(2*PI*R2)/R2
      FACR=2*SR*COS(PI*L/LMDA)
      RESIST=(((SR1*CA1+SR2*CA2-FACR*CA)*SY)/TERM+(FACR-SR1-SR2)*SZ)*
     1SIN(2*PI*(0.5*L/LMDA-ABS(S)))/S
      RETURN
      END
```

```
      FUNCTION REACT(S)
C REQUIRED FOR DIPOLE
      COMPLEX ADA
      REAL L,LMDA,K
      COMMON /IMP/ ZO,YO,L,DLPRI,LMDA,NN,WIRE,K,ADA,COSDL
      PI=3.14159265
      SZ=S*COS(2*DLPRI)
      SY=-S*SIN(2*DLPRI)
      TERM=YO+SY
      ROW2=(YO+SY)**2
      CA=ZO+SZ
      CA1=CA+0.5*L/LMDA
      CA2=CA-0.5*L/LMDA
      R=SQRT(ROW2+CA**2)
      R1=SQRT(ROW2+CA1**2)
      R2=SQRT(ROW2+CA2**2)
      CR=COS(2*PI*R)/R
      CR1=COS(2*PI*R1)/R1
      CR2=COS(2*PI*R2)/R2
      FACX=2*CR*COS(PI*L/LMDA)
      REACT=(((CR1*CA1+CA2*CR2-FACX*CA)*SY)/ROW2+(FACX-CR1-CR2)*SZ)*
     1SIN(2*PI*(0.5*L/LMDA-ABS(S)))/S
      RETURN
      END
```

APPENDIX E

SHIPBOARD ANTENNA DYNAMIC SIMULATION EQUATIONS

This appendix presents the development of ship motion equations as functions of sea state and relative direction of the sea. Ship motion is resolved into parameter variation. The values for time varying parameters are used in the compute loop for the dynamic simulation.

The ship-ocean combination is modeled as follows:

1. The ship will roll sinusoidally 8 degrees per sea state if the sea is on the beam, ie. from 090° R or 270° R.

2. The ship will pitch sinusoidally 2.4 degrees per sea state if the sun is on the bow or stern, ie. from 000° R or 180° R. (This represents a small naval combatant ship)

3. Sea state and direction is resolved into ship motion:

Vertical Whip or Sloping Long Wire

$$AA = 2 \cdot L \cdot SIN\ (\Delta\Theta 1/2)$$

$$BB = 2 \cdot L \cdot SIN\ (\Delta\Theta 1/2)$$

$$CC = AA^2 + BB^2$$

$$DD = L^2 - (CC/2)^2$$

$$|\Delta_{\Theta_3}| = 2.\tan^{-1} \frac{(CC/2)}{DD}$$

$$\Delta_{\Theta_3} = |\Delta_{\Theta_3}|$$

$$\Theta'(t) = \Theta'(0) - \Delta_{\Theta_3} \qquad \text{(TILT)}$$

$$SIN\ \Delta_{\Theta_3} = SIN\ \Delta\Theta\ SIN\ \Delta_{\Theta_3}$$

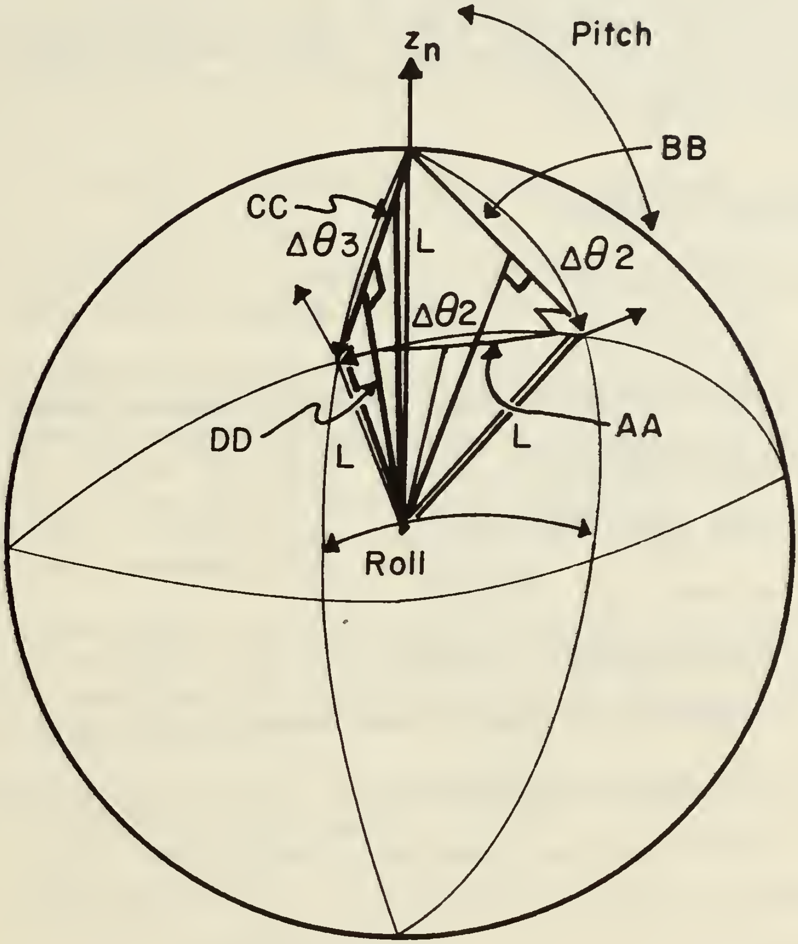
$$COS\ \Delta\Theta = (1 - SIN^2\Delta\Theta)^{1/2}$$

$$|\Delta\phi| = \tan^{-1}\ {}^{SIN\ \Delta\phi}/COS\ \Delta\phi \qquad \text{(azimuth change)}$$

$$\text{Wave} = 8 \cdot \text{SEA} \cdot \text{SIN}(wt)$$

Roll: $$\Delta\theta 1 = \text{Wave} \cdot \text{SIN}(\text{CRS.}\ \pi/180)$$

Pitch $$\Delta\theta 2 = 0.3 \cdot \text{wave} \cdot \cos(\text{CRS.}\ \pi/180)$$



Dipole: $$\theta'(\tau) = \theta'(0) - \Delta\theta 2 \qquad \text{(tilt)}$$
$$H(\tau) = H(0) \cdot \cos(\Delta\theta 1) \cdot \cos(\Delta\theta 1) \quad \text{(height)}$$

if: $\Delta_{\Theta_1} > 0$ and $\Delta_{\Theta_2} > 0$ $\qquad \Delta\phi = |\Delta\phi|$

$\Delta_{\Theta_1} < 0$ and $\Delta_{\Theta_2} > 0$ $\qquad \Delta\phi = -|\Delta\phi|$

$\Delta_{\Theta_1} > 0$ and $\Delta_{\Theta_2} < 0$ $\qquad \Delta\phi = (\Pi - |\Delta\phi|)$

$\Delta_{\Theta_1} < 0$ and $\Delta_{\Theta_2} < 0$ $\qquad \Delta\phi = -(\Pi - |\Delta\phi|)$

$\phi'(t) = \phi'(0) - \Delta\phi$

<u>Definition of terms</u>:

Δ_{Θ_1} - ship roll

Δ_{Θ_2} - ship pitch

Δ_{Θ_3} - tilt of whip or long wire caused by ship motion (whip)

wave - sinusoidal wave

ω - wave radar frequency

$\Theta'(t)$ - antenna tilt (Dipole)

$h(t)$ - antenna height (Dipole)

$\Delta\phi$ - variation in antenna train caused by ship motion (whip)

$\phi'(t)$ - antenna train (whip)

CRS - Direction of sea relative to ship's bow

APPENDIX F

OPERATING INSTRUCTIONS FOR U.S. NAVAL POSTGRADUATE SCHOOL GRAPHICS COMPUTER LAB

This appendix gives step by step operating instructions required to use the antenna patterns graphics program at the Naval Postgraduate School. Use of the graphics library program "GATED" and computer light-off procedures are covered in the operators manual and laboratory memoranda and are not included in this appendix.

1. Light-off SDS digital computer in accordance with operating instructions.

2. Light off ADAGE graphics computer in accordance with operating instructions and load library program "Gated".

3. Load the program in the XDS-9300 computer. If an overlayed version of the program is used, the entire program may be loaded. If an overlayed version of the program is not used, computer memory limitations allow loading only two antennas at a time. The input resistance branches, gain branches, and required subroutines for the antennas desired should be loaded along with the main program. A missing lables warning will result but the program may be operated if only antennas loaded are called.

4. When the input light on the teletype is lighted type IDEV = 1* if ADAGE 1 is to be used or IDEV = 2* if ADAGE 2 is to be used. Pushing the carriage return will cause the data input format to be displayed at the graphics terminal.

5. Enter parameters and option commands using "Gated" text editing techniques. Inputs should be as follows:

a. Under ANTN enter one of the following to specify antenna type:

0001	Tilted Dipole
0002	Vertical Whip
0003	Vertical Whip with Ground Screen
0004	Inverted L
0005	Sloping Longwire
0006	Sloping Vee
0007	Horizontal Rhombic
0008	Vertical Half Rhombic

b. Under LENG enter length in format F4.1

c. Under HGHT enter height in format F4.1

d. Under PHIP enter ϕ' in format I4

e. Under THEP enter Θ' in format F4.0

f. Under FREQ enter f in format F4.0

g. Under EPSL enter ϵ_r in format F4.1

h. Under SGMA enter σ in format F4.2

i. Under PHI enter the observation azimuth angle for the vertical pattern using format I4.

j. Under THET enter the observation zeniuth angle for the horizontal pattern using format I4.

k. Under PARM enter 0000. If reinitialization is desired to erase a manually entered pattern, enter 0001. If Log Gain patterns are desired, enter 0002.

l. Under ISTH and ISTV enter 0000. If saving the pattern that will be computed in the current compute cycle is desired, enter 0001. If it is desired to keep the pattern in the save array, these option commands must be set to 0000 in the succeeding compute cycle.

m. Under IRCL enter 0000. If displaying saved patterns is desired, enter 0001.

n. Under HGTT enter 0000. Entering 01.0 will multiply the value of sigma by .1. Entering 02.0 will multiply the value of sigma by .01.

o. Under ALPH enter α in format I4.

There are two unused data blocks which no operation edits must be made to finish the data input processor.

6. Axes and a blank graphics data block will now be displayed on the terminal screen. A pattern desired for comparison purposes may be entered in this block using manual graphics editing techniques. To terminate this processor operation, push the end edit button on the function switch panel. This processor may be terminated without entry if desired.

7. The antenna patterns selected will be computed and the horizontal pattern displayed on the upper axis. Pushing the end edit button will cause the vertical pattern to be displayed on the lower axis.

8. If the display saved patterns option has been selected, pushing the end edit button two additional times will cause the vertical and horizontal patterns to be superimposed on the current vertical and horizontal patterns. The program will, then, return to the enter parameters and option commands processor. If recall has not been selected, the program will return to the enter parameters processor from terminating the vertical pattern display processor termination (end edit).

The compute cycle is now repeated. Ending the program must be done in accordance with laboratory operating instructions. Figures 4.1 thru 4.20 are the entries for the examples of section 4.

p. Under ISEA enter sea state in I4, if a dynamic display is desired for dipole, whip or longwire antennas. If dynamic display is not desired, enter 0000.

q. Under ICRS enter relative direction of seas if dynamic display is desired.

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13. ABSTRACT

An interactive computer graphics antenna gain pattern computation and display program for real-world antenna systems is presented. The use of the program as a teaching tool at the Naval Postgraduate School is discussed. Methods for applying the program for the synthesis and design of complex antenna systems are indicated. Research applications include techniques for rapid inspection of gain equations of newly developed antennas. A ship motion model is developed for studying the effects of electrical geometry variations caused by ship motion in heavy seas on maritime antenna systems and a dynamic presentation of pattern variations is made.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Antennas						
Antenna Gain						
Antenna Patterns						
Computer Program						
Interactive Computer Solution						
Graphics Display						